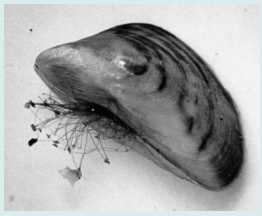
Zebra and Quagga Mussels

Randy Westbrooks

Zebra Mussel

Dreissena polymorpha



Fred Snyder

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 can be recognized from other mussels by its triangular shape and one flat edge where its byssal threads (for attaching to hard surfaces; see inset photo) emerge. However, it is not as easily distinguished from quagga mussels, as both have byssal threads, which is a key feature for distinguishing them from other non-dreissenid mussels.

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. At maturity, 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 United Kingdom, 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). From there, the mussels were transported into many Southern California reservoirs via infested Colorado River water that runs through aqueducts to the reservoirs, providing the region with half of its drinking water. They also spread, presumably via boats, to a single site in central California, the San Justo Reservoir. 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: zebra and quagga mussels can both produce millions of 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

Carrie Culver

Zebra and quagga mussels are the only freshwater mollusks that are able to produce extremely strong byssal threads and attach to underwater surfaces.

larvae called *veligers*. Veligers are planktonic (free swimming) for several weeks before developing into the juvenile stage, when 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. 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 distinctive flat edge of the zebra mussel could increase its stability and grip on hard, flat surfaces.

The optimal temperature for zebra mussel reproduction is 57 to 61 degrees F (14 to 16 degrees C), while the minimum spawning temperature for quagga mussels is much lower, at 48 degrees F (9 degrees C). In one case, a female quagga mussel with mature gonads was found in Lake Erie at a temperature of 41 degrees F (4.8 degrees C)! The lower temperature tolerance of quagga mussels enables it to invade deeper, cooler waters than the zebra mussel, and to reproduce more often throughout the year, including winter months, in some warmer climates.

Differences in temperature tolerances and ability to attach to substrates 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 five 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

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.

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

Quagga mussels are named after *Equus quagga quagga*, an extinct relative of the common or plains 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 in the Great Lakes.

Zebra and quagga mussel comparison chart

Trait	Zebra Mussels	Quagga Mussels
Shell	Triangular shape, underside flat. Obvious ridge between side and bottom. When placed on its ventral side, it will remain upright.	Rounder sides, convex underside. No ridge. When placed on its underside, the quagga mussel will topple.
Color	Variable colors and patterns, usually dark.	Pale near hinge, dark concentric rings on the shell.
Underside	Large groove in middle of flat side; allows tight hold on rocks.	Small ventral groove near the hinge.
Depth in lake	3 to 98 feet; rarely found below 50 feet.	3 to 540 feet; expected to go deeper over time.
Temperature tolerance	54° to 68° F (12° to 20° C)	39° to 68° F (4° to 20° C)
Spawning temperature	Minimum 56° F (13.2° C); can survive in stagnant water with uniform temperature but cannot reproduce there.	Minimum 50° F (10° C); a female quagga mussel with mature reproductive organs was found in Lake Erie at a temperature of 42° F (5.5° C).
Habitat occupied	Lakes, waterways, and ponds, and rivers with currents less than 2 m/sec.	Lakes, waterways, and ponds.
Substrate colonized	Hard only	Hard and soft

After A. Elicierto, *Milwaukee Journal Sentinal.* Sources: USGS; Sea Grant Pennsylvania; Oregon Sea Grant.

need calcium for *osmoregulation* (maintaining the correct salt and water balance in their blood). Calcium is also used for shell and gamete production. Quagga mussels have similar, but not well defined, requirements for calcium. 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.

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 and other systems.

HOW THESE SPECIES GOT HERE

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

HOW THESE SPECIES SPREAD

Transport vectors for juvenile and adult "attached" mussels include contaminated machinery, aquarium dumping, and, most importantly, trailered boats with mussels attached to the hulls, motors, or engine-cooling intake pipes. It is estimated that, given average summer temperature and humidity conditions, zebra mussels attached to a trailered boat could survive an overland trip for up to several days, and even up to several weeks under high humidity and cool temperatures. Mussel *larvae* are easily transported in ballast water of ships and recreational boats, in bilge pumps, through fish stocking from aquaculture, on scientific sampling equipment, or on scuba gear. Passive downstream

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.

transportation of larvae through infested rivers and aqueducts 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 (the tiny or microscopic plants and animals in the water column) form the base of the food web. By filter-feeding large amounts of plankton, zebra and quagga mussels remove a major food source for many other organisms in the lake. 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, can make the lake bottom much more productive than normal. Bottom-dwelling organisms, such as crayfish and plants, benefit from 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 *benthification*.

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.*)

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 and there is evidence of decreased fish populations due to mussel infestations. 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*.

The consequences of benthification

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.

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 625 miles (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 shutdown 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 docks, and it can accelerate deterioration of dock pilings. Shell material can cut angler's lines, and the risk of personal injury from cuts is high. Control efforts can cost facility operators about billions of 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 and these impacts have been documented in the Great Lakes for particular fish.

CULTURAL SIGNIFICANCE

Some people appreciate the increased water clarity resulting from zebra and quagga mussel filter-feeding; however, they mistakenly equate clarity with cleanliness. Zebra mussels filter only the plankton, but leave behind pollutants and toxin-producing cyanobacteria.

LAWS CURRENTLY IN PLACE

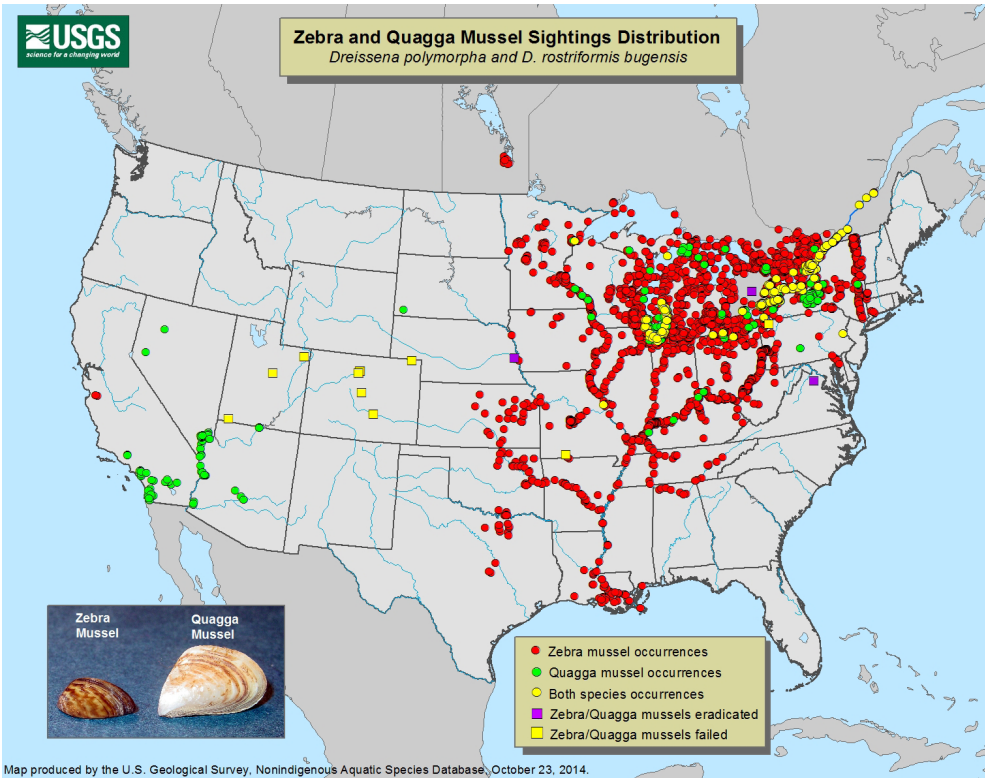
- The National Invasive Species Act of 1996 requires ballast water management in an effort to prevent the introduction and further spread of nonindigenous species in U.S. waters.
- In Washington, California, and Oregon, zebra and quagga mussels are classified as a prohibited species and are therefore illegal to possess. In Washington, it is illegal to transport plant material, which may have zebra and/or quagga 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!

Samuel Chan, Oregon Sea Grant

Shoe encrusted with quagga mussels after just 3.5 months.



Zebra and quagga mussels are spreading rapidly across the United States. Only recently in 2007 were they discovered on the west coast. The quarantine calculator used in this activity will help students learn about modeling while they help prevent the spread by determining how long to dry a boat before launching. Map produced by the U.S. Geological Survey, Nonindigenous Aquatic Species Database, October 23, 2014.

Also, 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 that can cut feet or fishing lines, as well as odors from decomposing mussels on beaches.

MANAGEMENT STRATEGIES

Prevention

Once mussels invade a water body, they are virtually impossible to completely eradicate. Therefore, prevention efforts are focused on reducing their introduction to other areas 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 hull coatings. Select the coating carefully since some, such as copper and zinc, are toxic and should be used sparingly, if at all. Nontoxic coatings, such as silicone-based coatings, are also available. Piping made of certain materials (copper, brass, galvanized metals) is also toxic to mussels and thus will help reduce attachment of mussels to various parts of your boat or to lake infrastructure.

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 pesticides don't kill zebra and quagga mussels quickly, 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 for food and concentrate them in their gut at lethal levels. In a controlled environment, 60 percent 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 quagga mussels and appears to have minimal impact on other aquatic organisms. This product, however, has not been approved by the U.S. 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.*

- Apply chemical molluskicides, such as chlorine or chlorine dioxide.
- Remove organisms manually by picking or high-pressure wash.
- Dewater or desiccate surface with freezing or heated air.
- Use thermal techniques, such as steam injection or hot water. When possible, use water at a temperature of 140˚ F (60˚ C) at the hull, or about 155˚ F (68˚ C) at the nozzle, which will kill the mussels. Dry the boat as much as possible.
- Apply acoustical vibration or electrical current.
- Use filters.
- Apply coatings: toxic (copper, zinc) and nontoxic (silicone-based).
- Use toxic constructed piping (copper, brass, or galvanized metals).
- Inject CO_2.
- Apply ultraviolet light.
- Subject organisms to anoxia/hypoxia.
- Flush.

WHAT YOU CAN DO

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: to the touch, small mussels feel like small bumps that rotate.
- 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.

100th Meridian

Zebra mussels.

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
- **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.

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

Aquatic Invasive Species Eradication and Control

California Sea Grant

This site is intended to assist lake managers and collaborating groups in preparing and implementing eradication and control tactics for aquatic invasive species.

http://ca-sgep.ucsd.edu/quaggazebra_mussel_control

Aquatic Nuisance Species (ANS) Task Force

Protect Your Waters and Stop Aquatic Hitchhikers!

Information on aquatic hitchhikers, prevention, control.

www.protectyourwaters.net/

Invasive Species of Oregon

Salem *Statesman Journal*

Ten-month series investigating invasive species. Includes various articles and videos, 2007–2014. Search archive for several articles.

http://pqasb.pqarchiver.com/statesmanjournal/results.html?st=basic&QryTxt=Invasive%20species

Nuisance Species Project

Pacific States Marine Fisheries Commission, Aquatic Invasive Species

http://www.westernais.org/

Oregon State Marine Board

Oregon Clean Marina Program

Part of OSMB's environmental programs, site provides extensive information on aquatic invasive hitchhikers on Oregon's waterways, permits, and boat maintenance and inspections.

https://www.oregon.gov/OSMB/boater-info/Pages/Clean-Marinas.aspx

Quagga and Zebra Mussels

California Department of Fish and Game

https://www.wildlife.ca.gov/Conservation/Invasives/Quagga-Mussels

School of Freshwater Sciences, University of Wisconsin–Milwaukee

http://www4.uwm.edu/freshwater/

Zebra/Quagga Mussels

100th Meridian Initiative

Informational brief on western quagga mussels.

http://www.100thmeridian.org/zebras.asp

Videos

Quagga & Zebra Mussels Invade California Waters

California Department of Fish and Game

Video by CDFG, available on scvtv. com (43:43; originally aired on January 30, 2012).

http://www.scvtv.com/html/cdfg013012mussels.html

Quagga and Zebra Mussels

Salem *Statesman Journal*

Invasive Species of Oregon series. Wildlife official Jim Gores demonstrates how to inspect their boats in order to prevent invasive quagga and zebra mussels from spreading to Oregon (3:24).

http://archive.statesmanjournal.com/VideoNetwork/49609787001/Quagga-and-Zebra-mussels

Quagga Mussels

Oregon Public Broadcasting

Video produced by OPB's Oregon Field Guide (9:49; originally aired on October 4, 2007).

http://www.opb.org/television/programs/ofg/segment/quagga-mussels/

Quagga Mussels Feeding—Speeded Up 10x

University of Wisconsin Sea Grant

Selective filtering in action: Zebra mussel expelling alga as pseudofeces (1:19; uploaded June 11, 2009).

https://www.youtube.com/watch?v=9SK5amoShPE

The Silent Invasion

Oregon Public Broadcasting in partnership with the Oregon Invasive Species Council and The Nature Conservancy

Video by OPB and partners focusing on invasive species in Oregon (56:06; originally aired on April 22, 2008).

http://watch.opb.org/video/1274375861/

Articles in the News

ODFW boat inspectors decontaminate pontoon boat carrying invasive quagga mussels

Oregon Department of Fish and Wildlife.

http://www.dfw.state.or.us/news/2014/may/052114b.asp

Bill to keep mussels out of lakes

Denis Cuff, April 11, 2008. *Contra Costa Times*.

http://www.contracostatimes.com/environment/ci_8897290?nclick_check=1

Crustacean-sniffing dogs fight invaders for fish and game

April 3, 2008. *SF Gate.*

http://www.sfgate.com/sports/article/Crustacean-sniffing-dogs-fight-invaders-for-Fish-3221513.php

Formidable invasive species won't be easy to keep out of Great Lakes

Dan Egan, July 26, 2014. *Journal Sentinal*, Milwaukee, Wisconsin.

Second of four parts of series, A Watershed Moment, on aquatic invasive species in the Great Lakes region.

http://www.jsonline.com/news/wisconsin/formidable-invasive-species-wont-be-easy-to-keep-out-of-great-lakes-b99297517z1-267014431.html

Zebra Mussels Make New Rules

Patrick Kendall, September 10, 1996. *Chicago Tribune*.

Describes food chain impacts and provides an example of how to write and share science with a more general audience.

http://articles.chicagotribune.com/1996-09-10/news/9609100221_1_zebra-mussels-striped-mollusk-lake-michigan

Educational sites

Zeke "the Prowler" Zebra Mussel

Illinois–Indiana Sea Grant

Nonindigenous species site for kids.

http://www.iiseagrant.org/NabInvader/Lakes/suspects/suspect_zeke.html

Online slide show about quagga mussels

The Great Lakes WATER Institute.

http://waterbase.uwm.edu/media/cruise/invasion_files/frame.html

Zebra Mussel Mania Traveling Trunk Adventure

Minnesota Sea Grant

Learn all about zebra mussels and other invasive species with this award-winning science kit and curriculum, for ages 8–14.

www.seagrant.umn.edu/educators/tt