Science, Service, Stewardship

NOAA FISHERIES SERVICE

Preventing Invasive Species: Decontamination of Invasive Bivalve Species

Zebra mussels colonize and completely cover a native mussel, leading to its demise. Many native mussels in danger of becoming extinct due to infestations of zebra mussels. (Photo credit Randy Westbrooks, U.S. Geological Survey, Bugwood.org).

Invasive mussels frequently settle in massive colonies that can block water intake pipes and threaten municipal water supply.

Background

Bivalves are easily recognized by their two-halved shells. Some well-known bivalves include clams, scallops, mussels, and oysters. All bivalves are aquatic, encompassing both marine and fresh-water species. Most species go through a free-swimming larval stage before taking on their characteristic adult form and lifestyle. The adult form may live attached to a substrate, burrow underground, or swim along the water bottom.

Invasive bivalve species cause extensive damage to our environment and economy. Bivalves are filter feeders that consume large portions of the microscopic plants and animals that form the base of the food web. Invasive bivalves can remove most of the food for microscopic zooplankton and filter feeders, which in turn support larval and juvenile fishes and other animals; bivalve species can effectively starve the native populations of infested lakes and rivers. The colonizing nature of invasive bivalves can also have a serious impact as their settlement may interfere with the feeding, growth, movement, respiration, and reproduction of native species. For example, zebra mussels can colonize a clam shell to such an extent that the clam cannot open its shell to eat. Some native bivalves have been found with more than 10,000 zebra mussels attached to them.

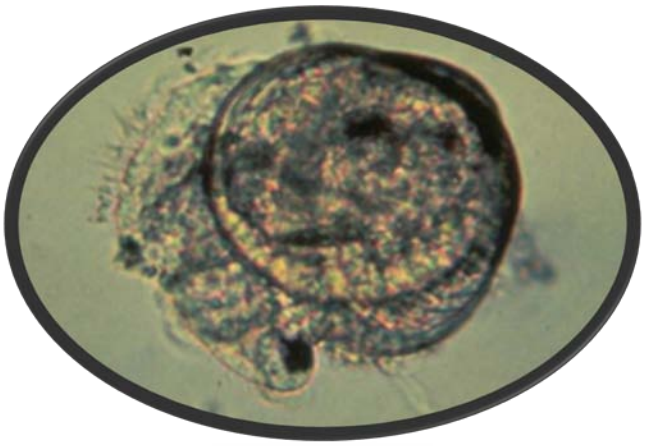
Bivalves are able to attach to almost any hard surface, either natural or manmade, making them notorious for their biofouling capabilities. Invasive bivalve species are capable of colonizing water supply pipes of hydroelectric and nuclear power plants, public water supply plants, and industrial facilities. As pipes are fouled, flow is restricted; therefore reducing the intake in heat exchangers, condensers, firefighting equipment, and cooling systems. Navigational and recreational activities can be negatively affected as invasive bivalve species colonize and cause damage to the hulls, engines, and steering components of boats and other recreational equipment. Beaches may become unusable as a result of the sharp shells and pungent odor characteristic of bivalve invasions.

Once established, invasive bivalve populations are nearly impossible to eradicate and control costs are extremely high. For example, Great Lakes officials have estimated that more than $5 billion will be spent in 10 years on zebra mussel control by manufacturing and municipal water intake facilities alone. Prevention is the best line of defense against invasive clams, oysters, and mussels. Proper preventative measures are important to avoid future bivalve introductions and avoid the high costs to the economy and our environment.

Decontamination Methods

Although numerous bivalve species have been introduced into the United States, scientific studies are needed to evaluate the effectiveness of control measures on specific species. The following decontamination methods pertain to the prevention of zebra and quagga mussels (*Dreissena polymorpha* and *D. bugensis*); however, preliminary studies have suggested that the recommendations listed below may also be effective in preventing the spread of other bivalve species.

In areas where invasive bivalve species are known to exist, *always* fully inspect and clean all vehicles and equipment used in water before transport into or out of the project site. In addition to adults, veligers (the immature bivalve life stage) can also attach to watercraft hulls, trailers, ropes, or other objects that come into contact with an infested water body. Since the veliger is microscopic, do not rely on visual inspection alone as they cannot be seen with the naked eye. Veligers are detectable only by feeling along all surfaces and inside holes and crevices. On a smooth surface, veligers will feel gritty, like sandpaper. As the veliger grows, it may become visible to the unaided eye, appearing as a speck.



Veligers can attach to anything that comes into contact with an infested waterbody. Since the veliger is microscopic, do not rely on visual inspection alone as they cannot be seen with the naked eye. (Photo credit: Ontario Ministry of Natural Resources)

Hot Water, High-Pressure Washing (Recommended for watercraft, trailers, and large equipment)

Using hot water, high-pressure washing is the most widely accepted method of cleaning invasive bivalves from surfaces. The combination of lethal temperature water, combined with the mechanical action of high pressure is very effective. Temperatures of 140°F are all believed to be 100 percent effective against all zebra and quagga mussel life stages; however higher temperatures (>160°F) may be necessary for thicker-shelled organisms, such as oysters. The following measures are recommended:

- Use a power washer unit that is capable of applying a flow rate of at least four gallons per minute with a nozzle pressure of 3,000 pounds per square inch, and able to supply water at 140 °F (or hotter) at the surface point of contact.
- To begin cleaning, reduce the nozzle water pressure by adjusting the power washer or using reduced pressure attachments. Do not attempt to remove or detach organisms from the surface using high water pressure at this point; the goal in this step is to kill the adults with hot water while they remain attached to the surface.
- Rinse the entire surface to be treated with heated water for at least 30 seconds; the exposure time at 140- 160°F is needed to effectively kill all life stages. To achieve this surface temperature, the operator may have to spray the surface for one to three minutes, depending on the size of the working area and the material composition of the surface. A hand-held infrared thermometer can be used to verify the surface temperature.
- After achieving a surface temperature of 140-160°F for 30 seconds, maintain a hot water temperature and increase the nozzle pressure high enough to detach organisms from the surface. Continue treatment on all exposed surfaces of the equipment.
- Finally, use a flushing attachment at reduced pressure to rinse all hard to reach areas and areas where high pressure may damage the equipment. Maintain a hot water contact time of two to three minutes within these areas to ensure that all individuals are killed on the surface, since it may not be possible to remove them from hidden or sensitive areas.
- This treatment should be performed in a staging area designated for cleaning operations. Water runoff must be managed with the use of berms or other containment systems to prevent the spread of contaminated materials outside of the washdown location.

Thermal Decontamination
(Recommended for field equipment and engines)

- Heating is generally regarded by most authorities as the most effective and easy to use of the control methods. The use of steam, autoclaving, or boiling to achieve temperatures of 140°F are all believed to be 100 percent effective against all zebra and quagga mussel life stages; however higher temperatures (>160°F) may be necessary for thicker-shelled organisms, such as oysters.
- Water temperature used during hot water washing or rinsing must be maintained at >140-160ºF at surface contact for one to three minutes' exposure time to bring the surface temperature up to 140-160°F for 30 seconds. Use a hand-held infrared temperature reader to verify surface temperature.
- It is possible for bivalves to live inside the cooling system of watercraft engines and become a source of contamination when it is operated in un-infested waters. Veligers can enter the engine through the cooling water intake, become attached inside the system, and grow into adults.
- For engine decontamination: at the water jacket, transfer the engine heat to the cooling water. By transferring the engine heat to at least 140 °F, the circulating cooling water is on the "hot" side of the cooling system—from the water jacket to the water outlet ports—where the heated cooling water should kill any organisms present.
- Running a chemical solution, such as a bleach solution, through an engine to decontaminate it may violate the terms of the engine's warranty, or otherwise damage the engine. Chemical treatments on engines are **not** recommended, unless specified by the manufacturer. Further, chemical treatments are not effective for engine decontamination because adults are able to sense a toxic external environment and close up for extended periods of time.

Invasive bivalves can be transported via boat hulls, motors, ballast water, live bait and other gear, including clothing. Thoroughly inspect, clean, and dry all of equipment that contacts the water (Photo credit: University of Nevada)

To prevent further invasions of invasive mussels, all watercraft and equipment must be fully inspected and decontaminated before transport into or out of the project site. (Photo credit: California Parks Companies).

Desiccation

Desiccation is effective if sufficient time is allowed. Drying times capable of killing bivalves vary according to the month of the year, location, and relative humidity. For example, many species can survive five days out of water in hot weather and up to 30 days in cool, wet weather. (Drying time for specific locations can be calculated at: http://www.100thmeridian.org/Emersion.asp.) No single drying time estimate can ensure a complete kill for all situations and a complete inspection should always be preformed prior to entering a new waterbody.

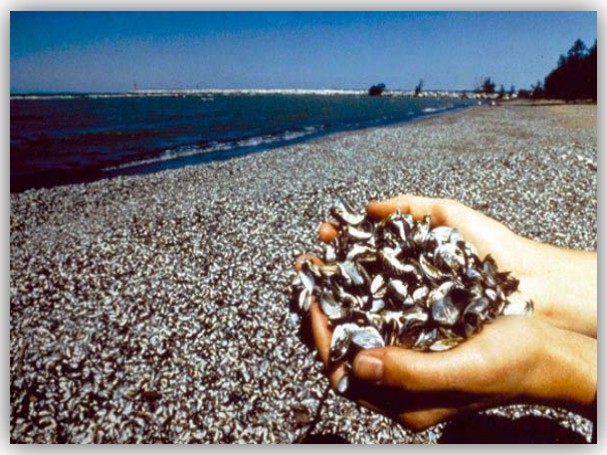
Chemical Decontamination

The successful use of chemical decontamination depends on the species' life stage, the type of decontamination chemical, the concentration used, and the contact time. Adult bivalves can close up and survive for extended periods of time under toxic external conditions; accordingly, chemical decontamination as a means to kill adult forms may require a contact time as long as 10 days. Because of this resistance action, chemical solutions are usually better suited for veliger treatment.

Commonly used chemical decontamination methods (with specific contact times) for veligers are:

- Diluted household bleach solution (> 5% sodium hypochlorite) at a concentration of three ounces of bleach per five gallons of water for a minimum of one hour.
- Undiluted white vinegar for 20 minutes.
- 1% potassium permanganate solution at 24-hour exposure.
- 5% quaternary ammonium solution for 10 minutes.
- 250 mg/L ROCCAL (benzalkonium chloride) for 15 minutes
- 500 mg/L hydrogen peroxide for 60 minutes
- 167 mg/L formalin for 60 minutes

The use of chemical treatments sometimes poses disposal and wastewater concerns. If chemical treatments are used, local standards of waste disposal must be followed. Since local regulations for chemical disposal may vary, always contact a local chemical waste management facility, the Environmental Protection Agency, or refer to the Material Safety Data Sheet for recommendations on proper disposal prior to use of any chemical. Some state states may also require certification or licensing for personnel who use chemical treatments. Finally, some solutions may cause corrosion on metal surfaces and electrical connections; be sure to follow all label restrictions and manufacture guidelines. Following treatment, rinse all surfaces with clean water and dry thoroughly.



The intensive filtering activity of invasive mussels can drastically alter aquatic ecosystems by increasing water clarity and decreasing the food available to native species. (Photo credit: NOAA)

Invasive bivalves can be transported via boat hulls, motors, ballast water, live bait and other gear, including clothing. Thoroughly inspect, clean, and dry all of equipment that contacts the water (Photo credit: University of Nevada).

Freezing

Many bivalve species have a relatively low tolerance to freezing. Studies have reported 100 percent mortality when individual zebra mussels were exposed to 14 °F for as little as 80 minutes. However, clusters of mussels were more tolerant than individuals, and the corresponding freezing mortality exposure time at 14 °F appears to be at least four hours.

Physical

Crushing is an effective way to kill individual adult bivalves, but it is not effective against veligers or juvenile life stages, nor is it practical for use over large surface areas. Crushed adult remains should also be exposed to a hot water soak treatment prior to final disposal.

Common Invasive Bivalve Species within the United States

Zebra mussel (*Dreissena polymorpha*)

Distinctive Features: Specimens exhibit a D-shaped shell, often with dark and light-colored stripes; however, the pattern varies greatly to where there are no stripes, only dark or light colored shells. Adults reach a maximum length of about 50 mm.
Habitat: Prefer temperate, shallow (<50 feet) freshwaters; can inhabit brackish waters ranging from 0.2 to 2.5 ppt.
Native Range: Black, Caspian, and Azov Seas
Date of arrival: 1988 (Lake St. Clair)

Above: Range of color variations of the **zebra mussel** (*Dreissena polymorpha*) Photo Credit: U.S. Geological Survey Archive, U.S. Geological Survey, Bugwood.org

False dark mussel (*Mytilopsis leucophaeata*)

Distinctive Features: Specimens are small, rarely exceeding 2cm in length. Adult mussels are dark brown while juveniles have a striped pattern on their outer shells. Often confused with the zebra mussel (*Dreissena polymorpha*); however, the shell is less angular and exhibits an internal tooth-like projection inside the end of the shell.
Habitat: Occupies both freshwater and brackish estuary habitats Prefers salinity ranges from 3 to 15 ppt
Native Range: Gulf of Mexico
Date of arrival: 1996 (Hudson River)

Left: Inner and out shell of the **false dark mussel** (*Mytilopsis leucophaeata*)
Photo credit: Annick Verween, University of Gent

Quagga mussel (*Dreissena bugensis*)

Distinctive Features: Shell color is usually light tan to almost white, with black, cream, or white bands. They usually have dark concentric rings on the shell on their ventral side and are paler in color near the hinge. Often confused with the zebra mussel (*Dreissena polymorpha*); however the shell is rounder and slightly larger, reaching a maximum size of ~20 mm. The quagga also has a convex ventral side that can sometimes be distinguished by placing shells on their ventral side; a quagga mussel will topple over, whereas a zebra mussel will not.
Habitat: Prefer temperate, freshwaters; can inhabit brackish waters. Prefers deeper waters (>90 feet). Can tolerate a much wider range of temperatures, salinity, and water depths than zebra mussels.
Native Range: Dneiper River drainage of Ukraine and Ponto-Caspian Sea
Date of arrival: 1989 (Lake Erie)

Above: quagga mussel (*Dreissena bugensis***)**
Photo Credit: U.S. Geological Survey

Asian mussel (*Musculista senhousia*)

Distinctive Features: Small olive-green, yellow-green or greenish-brown mussel, which grows to a maximum length of 35 mm, but most commonly 10-25mm in length and up to 12mm in width. There are pale purple stripes radiating from the center of growth out to the hind margin of the shell; often there are dark purple-brown, wavy or zigzag, concentric lines or arcs surrounding the center of growth. The shell is smooth and shiny, and the interior is a purplish-gray, with the stripes often showing through the thin shell. The lower edge of the shell, opposite the hinge, is often slightly concave.
Habitat: Intertidal and subtidal, up to 20m depth on both hard and soft substrates.
Native Range: Asia - from Siberia, the Kurile Islands, Japan, Korea, and along the China coast to Singapore
Date of arrival: 1924 (Puget Sound)

Above: Inner and out shell of the **Asian mussel** (*Musculista senhousia*)
Photo credit: Photo credit: Huitres and Co.

Brown mussel (*Perna perna*)

Distinctive Features: Shell is smooth and elongate, reaching a maximum size of 90mm in intertidal zones and a maximum size of 120mm is reached in sublittoral zones. The shell is brown in color; thin around the edges and thickens posteriorly. Its best identifying characteristic is an internal "divided posterior retractor mussel scar."
Habitat: Restricted to subtidal zones of cooler subtropical rocky shores
Native Range: Africa, Europe, and South America
Date of arrival: 1990 (Port Aransas Pass, Gulf of Mexico)

Green mussel (*Perna viridis*)

Distinctive Features: The Asian green mussel is a large mussel 80-100mm in length; occasionally reaching 165mm. Juveniles have a distinctive bright green shell, which fades to brown with green edges in adults. The exterior surface of the shell is smooth with characteristic concentric growth rings and a slightly concave ventral margin. The inner surface of the shell is smooth with an iridescent pale blue to green hue. The ridge, which supports the ligament connecting the two shell valves, is finely pitted. The beak has interlocking teeth—one in the right valve, two in the left. Characteristic features of this species also include a wavy posterior and a large kidney-shaped abductor muscle.
Habitat: Generally inhabit intertidal, subtidal and estuarine environments with high salinity
Native Range: Widely distributed in the *Asia-Pacific region*
Date of arrival: 1999 (Tampa Bay**,** Florida)

Upper: green mussel (*Perna viridis*);
Lower: brown mussel (*Perna perna*)
Photo credits: Schooner Specimen Shells

Mediterranean blue mussel (*Mytilus galloprovincialis*)

Distinctive Features:
Specimens can grow up to 15cm, although typically only reach 5-8cm. The outside is dark blue or brown to almost black with relatively distinct growth lines. Shell is elongated oval-shaped with very narrow anterior and wide posterior; apex is slightly curved downwards at the left end.
Habitat: Typically requires rocky coastlines with a high rate of water flow.
Native Range: Mediterranean coast and the Black and Adriatic Seas.
Date of arrival: 1880 (Northern California)

Above: Mediterranean blue mussel (*Mytilus galloprovincialis*)
Photo credit: www.naris.go.kr

Charru mussel (*Mytella charruana*)

Distinctive Features: Specimens are usually less than 2 cm in length but may exceed 4 cm. The shell is mostly dark brown to black and has visible, semicircular rings; exhibiting a wavy dark (brown, purple, dark green) and light (cream) pattern. The interior of the shell is iridescent purple. This mussel can be distinguished from other common native mussels by the lack of distinct ridges (ribs) on the exterior of the shells.
Habitat: Euryhaline species; able to adapt to a wide range of salinities
Native Range: Mexico and South America
Date of arrival: 1986 (Jacksonville, Florida)

Pacific oyster (*Crassostrea gigas*)

Distinctive Features: Shell color is variable and usually pale white or off-white with purple streaks and spots. The two valves are unequal in size and shape; the left valve is slightly convex and the right valve is quite deep and cup shaped. Shell appearance varies widely depending on the environment where it is attached; a rounded shape with extensive fluting on hard substrata, an ovate and smooth shell on soft substrata, and a solid shape with irregular margins on mini-reefs. Mature specimens average 150-200mm, but can reach sizes over 400 mm long.
Habitat: Intertidal and subtidal zones; prefer hard surfaces in shallow or sheltered waters
Native Range: Pacific coast of Japan and Southeast Asia.
Date of arrival: 1875 (Puget Sound)

Above: Pacific oyster (*Crassostrea gigas*)
Photo credit: Linda Schroeder of The Pacific Northwest Shell Club
Above: Charru mussel (*Mytella charruana*)
Photo credit: Jacksonville Shells

Overbite clam (*Corbula amurensis)*

Distinctive Features:
The shell grows up to about 25 mm long and has the shape of a broad isosceles triangle. It lives partly buried in the sediment, with its hind third or half exposed above the surface. The exposed portion of the shell is often stained brown, in contrast to the buried portion of the clam which will remain white or yellow. The valves are thin and smooth although older specimens appear wrinkled on the shell surface. The right half of the shell is a bit larger than the left and slightly "overbites" it at the lower margin.
Habitat: Mostly subtidal, but it has been found in the intertidal zone. Highly tolerant species as it exists in salinities of 1-33 ppt, tropical to cold temperate waters, and all sediment types.
Native Range: Southern Siberia, Japan, Korea and China
Date of arrival: 1986 (San Francisco Bay)

Left: Overbite Clam (*Corbula amurensis)* Photo credit: Stillman Lab, UC Berkeley

Purple varnish clam (*Nuttallia obscurata*)

Distinctive Features: Specimens are oval shaped, with the posterior end slightly longer and more angular. The shell is relatively flat, with a large external hinge ligament, and grows to a length of approximately 5.5 cm. The outer surface of the shell is covered in a shiny brown coating (periostracum) which is usually worn off near the hinge. The interior surface of the shell is usually a uniform shade of purple, may sometimes appear white.
Habitat: Typically found in upper one third of the intertidal zone; prefers sand and gravel substrates. High tolerance for freshwater as the most abundant populations are found within areas of freshwater seepage.
Native Range: Japan, Korea and possibly China
Date of arrival: 1991 (Strait of Georgia)

Asian Clam (*Corbicula fluminea*)

Distinctive Features: Shells are oval to nearly triangular in shape, reaching 50 mm in length. The exterior of the shell is normally a yellow-green to brown in color with thick, concentric rings. Dark shell morphs exist but are limited to the southwestern United States. Internally they may be white or purple and have long, leaf-like lateral teeth on each side of the beak (native freshwater mussels have only lateral teeth on one side of the beak or lack them entirely).
Habitat: Freshwater, able to withstand slightly brackish water (5-8%). Prefers running water and sand or gravel substrates.
Native Range: Southern and eastern Asia and Africa.
Date of arrival: Asian clams were first documented on the West Coast in 1938

Above: Asian clam (*Corbicula fluminea*) Photo credit: Schooner Specimen Shells
Below: Purple varnish clam (*Nuttallia obscurata*) Photo credit: Linda Schroeder of The Pacific Northwest Shell Club

Suggested Resources:

Bonneville Hydroelectric Project Response Plan for Zebra Mussels (*Dreissena polymorpha*).
Athearn J. and Darland T. 2006. 100th Meridian Initiative. 33 pp. Available online at:
http://www.100thmeridian.org/ActionTeams/Columbia/CRB_ZMRR_090106_Appendix_H.pdf
The purpose of this plan is to provide the Bonneville Lock and Dam Project with information needed to rapidly respond to a reported introduction of zebra mussels.

Invasive Mussel Guidebook for Recreational Water Managers and Users: Strategies for Local Involvement.
California Resources Agency. October 2008. Available online at:
http://*www.resources.ca.gov/quagga/docs/QUAGGA_GUIDEBOOK.pdf*
Information presented in this guidebook deals exclusively with prevention and containment of invasive mussels and does not address control or eradication.

Pennsylvania Aquatic Invasive Species Monitoring Squad
Pennsylvania SeaGrant. Available online at: http://seagrant.psu.edu/zm/monitor/MonitoringManual2008.pdf
This document includes information on identifying zebra mussels and quagga mussels, choosing a monitoring site, recording and reporting data.

Protect Your Boat and Engine from Zebra Mussels
Wisconsin Department of Natural Resources.
Available online at: http://dnr.wi.gov/invasives/publications/pdfs/protectyourboat.pdf
This document describes simple and proactive steps boat owners may implement to protect their investment and prevent the spread of invasive species into more of Wisconsin's waters.

Protect Your Boat, Fight Quagga and Zebra Mussels: A Guide to Cleaning Boats
California Department of Fish and Game. October 2009. Available online at:
http://www.nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=4957
This guide was compiled specifically for boat owners and watercraft users. The information contains general guidelines for all boaters and a basic checklist for inspecting and cleaning boats and recreational equipment for Quagga/Zebra mussels

Protect Your Waters
Aquatic Nuisance Species Task Force. Available online at: http://protectyourwaters.org
This site provides recommendations for recreational users who want to help prevent the spread aquatic nuisance species.

Quagga / Zebra Mussel Infestation Prevention and Response Planning Guide
National Park Service, Natural Resources Program Center**,** Fort Collins, Colorado. May 2007. 43 pp.
Available online at: http://www.nature.nps.gov/water/quagga/QuaggaPlanningGuide_ext.pdf
This plan serves as a guiding document for park managers to provide for the prevention, early detection, and rapid response to quagga mussel infestations in western waters.

Rapid Response Plan for Zebra Mussels in the Columbia River Basin: A Comprehensive Multi-Agency Strategy to Expeditiously Guide Rapid Response Activities.
Heimowitz P., Phillips S. 2006. 100th Meridian Initiative.42 pp.
Available online at: http://www.100thmeridian.org/ActionTeams/Columbia/CRB_ZMRR_090106.pdf
The goal of the plan is to serve as a roadmap to guide rapid response following the detection of zebra mussels.

Rapid Response Plan for the Zebra Mussel in Massachusetts
Massachusetts Department of Conservation and Recreation. 2005. 13 pp.
Available online at: http://www.mass.gov/dcr/watersupply/lakepond/downloads/rrp/zebra%20mussel.pdf
This document provides a description of the zebra mussel, as well as containment and eradication measures.

Zebra Mussels
New Hampshire Department of Environmental Services. 2010 Environmental Fact Sheet WD-BB-17.
Available online at: http://des.nh.gov/organization/commissioner/pip/factsheets/bb/documents/bb-17.pdf
This factsheet Includes information on the distribution, ideal conditions, and control of zebra mussels in the Northeast.