Pacific Northwest Aquatic Invasive Species Profile

Quagga Mussel (Dreissena bugensis)

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Fish 423

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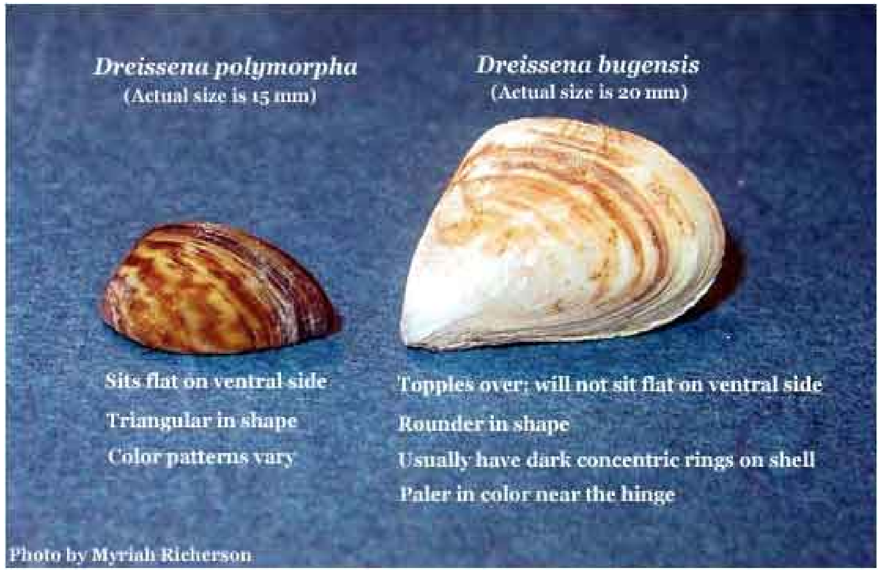


Scientific Classification

Kingdom: Animalia

Phylum: Mollusca

Class: Bivalvia

Subclass: Heterodonta

Order: Veneroida

Family: Dreissenidae

Genus: Dreissena

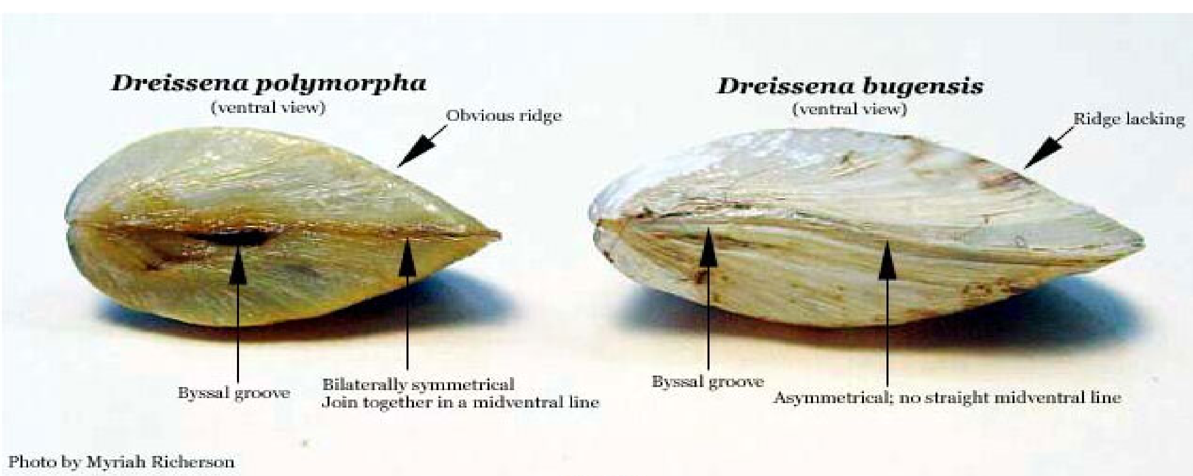
Species: *D. Rostriformis*

Subspecies: *D. r. bugensis*

Common Name: Quagga Mussel

Scientific Name: Dreissena bugensis

The Quagga mussel (Dreissena Bugensis) is a small freshwater mussel. It is 1 of 7 mussels in the family of *Dreissenidae*. The Quagga mussel is often mistaken for its more frequent relative the Zebra mussel *Dreissena polymorpha*. The mussel displays numerous morphs, with its shell patterns ranging from black, cream, or white bands (Benson et al. 2008). Stripes on the shell tend to be darkest near the opening and fade as they get closer to the hinge. There is 1 documented white morph lacking any stripes in Lake Erie (Benson & Richerson 2008). Due to its wide range in color the Quagga is best identified using its physical features. The Quagga mussel can be distinguished from the Zebra mussel by its convex ventral side (Benson et al. 2008). If placed on its ventral side it will fall over, while the Zebra mussel will not. The Quagga mussel is noticeably rounder with asymmetrical valves, where as the Zebra mussel if viewed from the front has bilaterally symmetrical valves.



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Life History and Basic Ecology

Life Cycle

Within a couple of days of fertilization Quagga mussels mature into veligers which are microscopic pelagic larvae. These larvae then drift for 3-4 weeks, during which they develop shells and feed using cilia (Benson & Richerson 2008). There is a 99% mortality rate during the 3-4 week planktonic stage (Benson & Richerson 2008). When the larvae are ready to settle they use byssal threads to attach to the selected substrate. They then mature into reproducing adults which can range from microscopic to 2 inches in length (Britton 2007). Adult Quagga mussels can live up to 5 years (Britton 2007).

Reproductive Strategies

Quagga mussels are dioecious meaning that each individual is either male or female (Benson & Richerson 2008). Both males and females can produce millions of eggs and sperm (Britton 2007). The species utilizes external fertilization through broadcast spawning of gametes (Benson & Richerson 2008). Quagga mussels will spawn all year if the water temperature is within its spawning range (Britton 2007). The Quagga mussel displays a wider temperature range than the Zebra mussel in terms of favorable spawning conditions (Orlova et al. 2005). The minimum spawning temperature for the Quagga mussel is 5°C (CRB 2008) compared to the minimum spawning temperature of Zebra mussel which is 12°C (Benson & Richerson 2008). The Quagga's optimal spawning temperature is 20°C (CRB 2008). It is believed that female Quagga mussels emit a species specific sperm attractant which provides for more efficient fertilization (Mills et al. 1996). This mechanism is useful in that both Quagga and Zebra mussels are normally present in the same habitat. Species-specific sperm attractant would limit hybridization which has been shown to be limited in larval survival (Mills et al. 1996).

Feeding Habits

Quagga mussels are filter feeders which can filter more than 1 liter a day per individual (Benson & Richerson 2008). Water is brought into the shell by the mussel's cilia and is then passed through its incurrent siphon (Benson & Richerson 2008). Filtration occurs within the incurrent siphon where Quagga mussels feed on phytoplankton, zooplankton, algae, and their own veligers (Benson & Richerson 2008). Unwanted material is cast out as pseudopheces using the same incurrent siphon, and filtered water is expelled by the excurrent siphon (Benson & Richerson 2008). Quagga mussel has demonstrated greater growth than zebra mussels at low food levels (Baldwin et al. 2002). This advanced growth may be due to the higher assimilation efficiency of Quagga mussels as well (Baldwin et al. 2002).

Environmental Optima and Tolerances

Depth: Quagga Mussels inhabit a wider range of depths than Zebra mussels with the deepest colonization occurring at 130 m in the Great Lakes (Mills et al. 1996). Quagga and Zebra mussels, “coexist at depths of 8-110 m, with only D. bugensis found at depths of 130 m” (Mills et al. 1996). Quagga mussels occur at a higher rate at deeper depths, however in its natural range it is found from 0-28m (Mills et al. 1996). Within its native range the max abundance of Quagga mussel is from 4-10 m (Mills et al. 1996).

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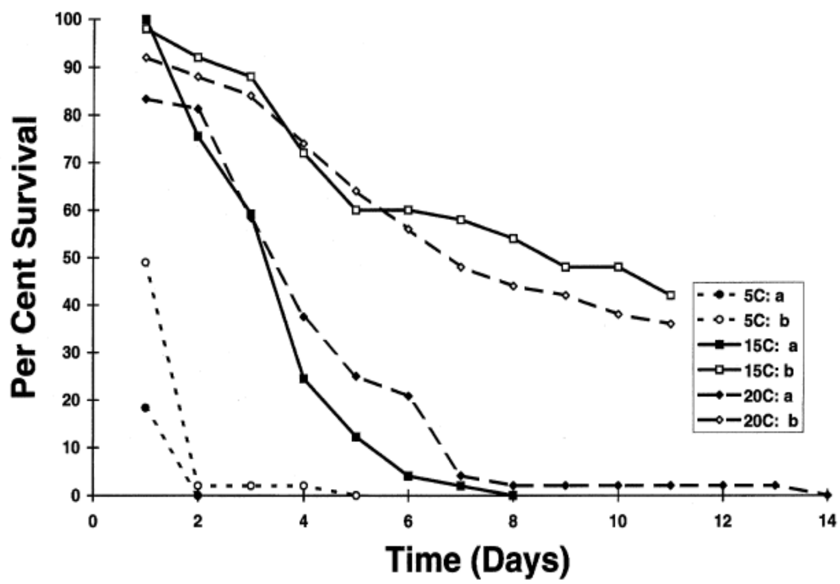


FIG. 3. Percent survival of quagga mussels (*Dreissena bugensis*) through time in replicated trials (a & b) when exposed to water temperatures of 30°C. The numbers 5, 15, and 20 indicate prior acclimation temperature in °C.

Salinity: Since Quagga mussels are a freshwater invertebrate they cannot tolerate high salinities. 5ppt is the maximum salinity that Quagga mussel in the United States can survive in (Mills et al. 1996). They can reproduce in salinities up to 3ppt. (Benson & Richerson 2008). In their native range Quagga mussels can tolerate salinities slightly higher salinities maxing out at 6ppt (Benson & Richerson 2008). Salinity is also the main controlling factor in Quagga distribution in its native range (Mills et al. 1996). Quagga mussel tends to show a lower salinity tolerance than Zebra mussel dominating only in salinities ranging between 1-.02 ppt (Mills et al. 1996).

Temperature: Since Quagga mussel is associated with deeper depths it makes sense that it is optimal operating temperature is lower than that of the Zebra mussel. Its optimal temperature is 16°C, 2 degrees below that of the Zebra mussel (Britton 2007). Both Quagga and Zebra mussels can tolerate freezing temperatures surviving up to, but not including, the freezing point(Britton 2007). The Quagga mussel can spawn in lower temperatures down to 9°C, thus increasing its spawning season (Britton 2007). Both mussels can tolerate high heat if acclimated, but in general, Quagga mussels have a lower thermal tolerance generally maxing at 25°C (Spidle et al. 1995).

Oxygen: Quagga mussels require little diffused oxygen in its aquatic habitat, needing less than 25% oxygen saturation (Karatayev et al. 1998). It is more tolerant of low oxygen levels than the Zebra mussel (Karatayev et al. 1998). Adult

Quagga mussels can survive out of water for 4-21 days while larvae can survive 3-5 days in standing water (Cohen & Weinstein 1998).

Water Velocity: Quagga mussels are generally found in reservoirs and slow moving rivers. They cannot establish in bodies of water where the water velocity exceeds 2m/sec (Britton 2007). This is because the pelagic larvae are unable to attach to the substrate.

Substrate: Quagga mussels can spawn on both hard and soft substrate where as Zebra mussels prefer hard substrates (Britton 2007). This ability to colonize soft substrate allows the Quagga mussel to colonize areas uninhabited by Zebra mussel.

Calcium: Quagga mussels require at least 25mg/l of calcium in order to maintain shell growth.

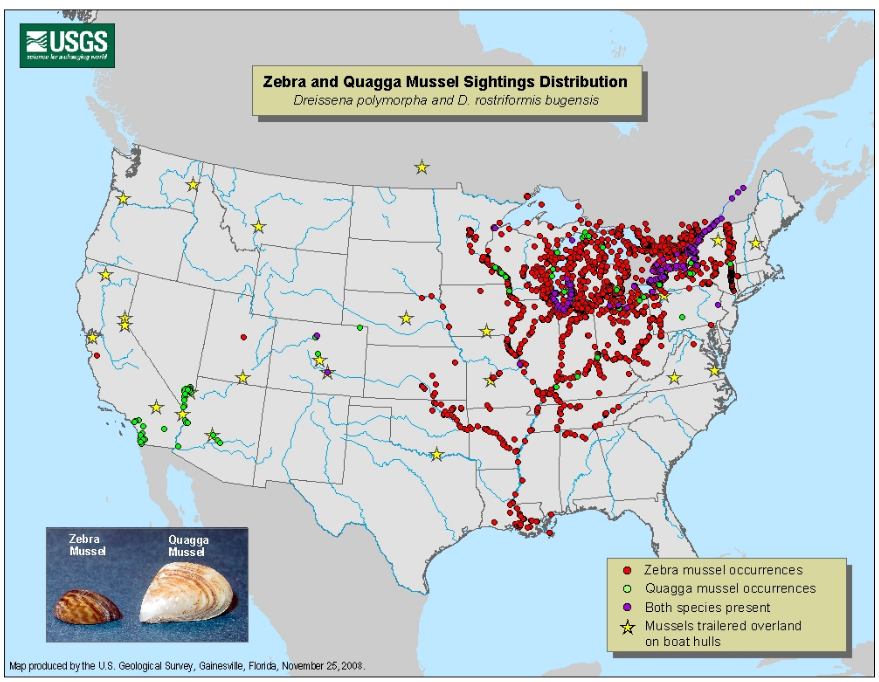
Biotic Associations

Predators: There are no known natural predators of Quagga mussel in the United States. The main consumers are water fowl such as ducks (Mackie & Schloesser 1996). Other predators include Red Ear Sunfish, Walleye, and Perch (Mackie & Schloesser 1996). None of these predators can consume enough mussels to limit the population. In its native range roach are the most significant predator able to consume large shells (Mackie & Schloesser 1996).

Parasites: The Quagga mussel is not known at this time to be a common vector for parasites (Mackie & Schloesser 1996). It can have protists, digeans, and nematodes, none of which show any detectable effect on Quagga populations (Mackie & Schloesser 1996).

Current Geographic Distribution

The Quagga mussel is native to the Dnieper River in the Ukraine (Mills et al. 1996). Established Quagga mussel populations in the United States are generally located near the Great Lakes inhabiting a total of 13 states



(Britton 2007). It has slowly been transferred to the west coast of the United States and is now found in Arizona, California, and Nevada.

History of Invasiveness

The initial enabler of Quagga mussel expansion was the damming of the Dnieper River which created reservoirs and canal, and connected the Dnieper to the Black Sea. The Quagga mussel's range did not immediately expand; there was a 40 year time lag before it was able to make it to the Black Sea (Orlova et al. 2005). Once the Quagga mussel established in the Black and Caspian Seas, it was transferred from Europe to the United States via ballast water (Cohen & Weinstein 1998). It was first sighted in the Great Lakes in September 1989 in Lake Eerie (Benson & Richerson 2008). Originally mislabeled a Zebra mussel; It was not until 1991 that it was recognized as a separate species (Benson & Richerson 2008). It was given the name "Quagga" which is an extinct relative of the African zebra (Benson & Richerson 2008). Quagga mussels were first sighted outside the Great Lakes in 1995 in the Mississippi River (Benson & Richerson 2008). The mussel expanded westward being found in Lake Mead in January 2007 (Benson & Richerson 2008). It was estimated that the mussel had been present for at least 2 years before it had been found (Stokstad 2007). Mussels were then found months later in the Colorado River and have now spread to at least 19 California Reservoirs (Benson & Richerson 2008). California has been the most westward state the Quagga has invaded, Oregon and Washington seem likely western states to become invaded in the near future.

Invasion Process

Pathways, Vectors, and Routes

Quagga range expansion was initially enabled by ballast water discharge (Benson & Richerson 2008). However the primary pathway of transportation within the United States primarily in the Pacific Northwest is Recreation (Cohen & Weinstein 1998). This is seen through bait bucket transfer, trailer and boat dispersal, and fish and aquatic plant sales (Cohen & Weinstein 1998). Quagga mussels can attach themselves to boats and trailers within 1-2 days of being in the water (The 100th Meridian Initiative), and they can be transferred over long distances. Larvae can also be transferred via bait buckets and any freestanding water in boats. Hatcheries are also modes of dispersal with Quagga mussels being found in the Nevada State Fish Hatchery and Willow Beach National Fish Hatchery (Britton 2007).

Factors Influencing Establishment and Spread

The Quagga mussel's life cycle and high environmental tolerances allow it to expand rapidly and throughout long distances. Its ability to survive outside of water allows for dispersal by watercraft, and its high reproduction rate and fast maturity allow it to colonize habitats rapidly. There are some limiting factors that can be found in the Pacific Northwest. The Columbia River is believed to be a likely target for Quagga invasion due to its frequent use by recreational boaters and its many access points. Though propagation seems likely, establishment is not guaranteed due to some limiting factors. Calcium levels in both the Columbia River and the Willamette River are low, and thus may inhibit establishment of Quagga mussel communities (CRB 2008). But calcium levels are hypothesized to be higher next to concrete, thus dams and other structures may provide viable habitat to be colonized. Water temperatures in the Columbia monitored by the Bonneville dam show that Quagga mussels would be able to spawn 7 months out of the year (CRB 2008). These environmental variables show that Quagga mussel invasion of the Columbia River is possible.

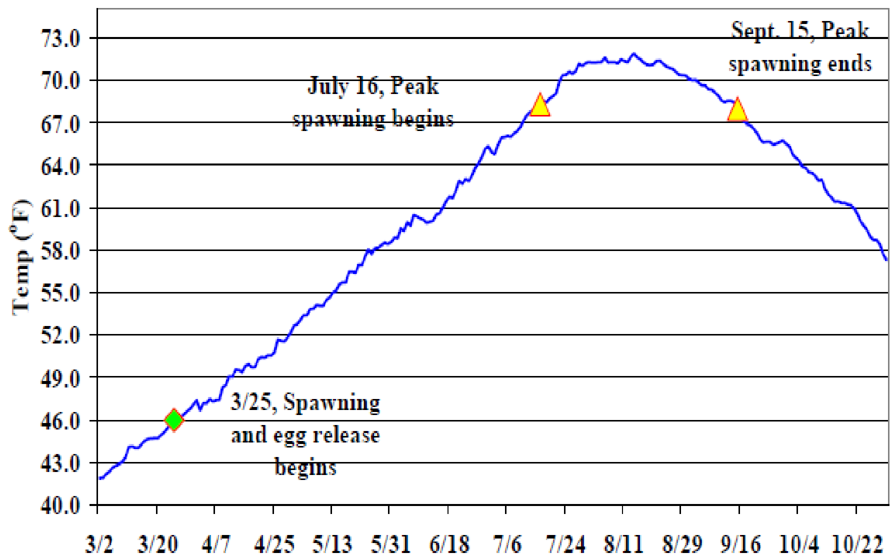


Figure 1. Daily average water temperatures at Bonneville Dam and John Day Dam Smolt Monitoring Facilities, 2000-2006 (Kovalchuk 2007).

Potential Ecological and Economic Impacts

The establishment of Quagga mussel populations in the Pacific Northwest poses several ecological threats to native species. Due to the ability of Quagga mussel to colonize most available substrates, it could pose a threat to native salmon and trout populations in local streams by colonizing spawning areas (CRB 2008). Quagga mussels would also likely out-compete native mussels by colonizing any available substrate as well as growing on the shells of native mussels (Benson & Richerson 2008). Populations of Quagga mussels can grow so large that their filter feeding can alter the ecosystem (Benson & Richerson 2008). Water filtration leads to reduced phytoplankton levels and consequently zooplankton levels. Water clarity increases and macrophyte growth increases (Benson & Richerson 2008). Pseudofeces discarded by Quagga mussels also poses a threat to local ecosystems. Pseudofeces is expelled by Quagga mussels and builds up and decomposes lowering oxygen levels (Benson & Richerson 2008). Lower oxygen levels lower the pH and the water becomes toxic creating dead zones in bodies of water (Benson & Richerson 2008).

The presence of Quagga mussel in the Pacific Northwest poses economical threats. State and private resources must be used for prevention, management, and eradication. From 1988-1995 facilities spent over $69 million dollars in expenses for invasive mussel prevention and management. Quagga mussels prefer hard surfaces for colonization and thus use water intake pipes to establish communities. This build-up of mussels in commercial pipes is called biofouling. It is estimated that between the years 1989 and 2004, $268 million dollars was spent on mussel related impacts to drinking water and power plants (CRB 2008). Estimates for mussel control on 13 hydropower facilities on the Columbia River over five years is projected to be over 52 million dollars (CRB 2008).

Current Management Efforts

In response to the spread of Quagga mussel from the Great Lakes, a comprehensive effort involving several agencies and groups was formed to prevent the westward spread of Quagga and Zebra mussels. This effort was deemed the 100th Meridian Initiative. Its main goals were to prevent spread of mussels using voluntary boat checks and cleaning, while also establishing rapid response plans in case either mussel was found in the western states. The Columbia River Basin Team has been formed as a part of the 100th Meridian Initiative. This team provides the main line of defense for the state of Washington serving generally the Columbia River, the most likely point of invasion. *The Columbia River Basin Interagency Invasive Species Response Plan: Zebra Mussels and other Dreissenid Species* was compiled by 4 states (Washington, Idaho, Oregon, and Montana) and over 36 different agencies and groups. The document prioritized prevention and education while forming scenario based rapid response plans for different types of bodies of water.

The state of California began active mussel prevention in 1993 by banning live Zebra mussels into the state while also inspecting watercrafts entering the state (Cohen & Weinstein 1998). Between 1993 and 1999, the California Department of Food and Agriculture found 18 trailer boats carrying zebra mussels (The 100th Meridian Initiative). The state of Washington began conducting mussel monitoring in 1997. In 2007, 131 plankton samples were taken from 92 sites, and settling plates were distributed among 90 sites (ANS Committee Report to the 2008 Legislature). Since it began monitoring, Washington has had 7 confirmed boats carrying Quagga or Zebra mussels try to cross the border (Pleus 2007). Washington designated the Quagga mussel a deleterious species meaning it is considered a danger to the environment. It was also deemed a prohibited species, which is the highest classification of risk. Thia label of prohibited species illegalized the possession, purchase, sale, and propagation of Quagga mussel within the state of Washington (7WAC 232-12-01-01701). Violation of this law can lead to a class C felony (Pleus 2007). In many cases, present laws are not sufficient for Quagga mussel prevention. For example, in 2007 a bill failed to get out of committee that would have required power washing of every boat entering the state (Willhelm 2008).

Expert Contact in the Pacific Northwest

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Management Strategies & Control Methods

There are 3 general management strategies for the invasion of Quagga mussel including prevention, control, and eradication. Prevention may be the most important strategy but 1 of the hardest to implement. This requires active monitoring at all entrances to a given state with boat inspections and cleaning. Education plays an important role in prevention by educating the public on likely vectors of introduction as well as consequences of invasion. Education has been primarily done through signage and pamphlets. Control and eradication methods are similar but vary on the level of use. Control is more reasonable due to the fact that eradication of established populations of Quagga mussels is nearly impossible unless the body of water is small and secluded. There have been some successful eradications, for instance in 2002, Virginia was able to eradicate Zebra mussels from a 12 acre quarry by treating it with potassium chloride for 3 weeks (CRB 2008). Success is usually determined by the type of body of water invaded.There are many different methods for controlling and eradicating Quagga mussel populations.

Methods

Thermal Shock

This treatment entails using water over 140°F to kill Quagga mussel. It is generally used at boat cleaning stations to quickly clean boats. It also used to flush commercial pipes to kill any mussels present inside that might foul them (CRB 2008).

Desiccation

Desiccation can be utilized as a control or eradication method. This is because invaded reservoirs can be completely emptied to eradicate Quagga mussels or they can be severely lowered in order to control Quagga mussel populations. This is an effective in that most mussels are found between 2 and 7m. Quagga mussels pose a problem since they can occur at deeper depths, meaning reservoirs would need to be lowered more than if Zebra

Table 1. Number of days to 100% mortality of adult zebra mussels aerially exposed to different levels of relative humidity and air temperature (McMahon et al, 1993).

	Days to 100 % Mortality at Air Temperature, °C		
Relative Humidity, %	**5**	**15**	**25**
95	26.6	11.7	5.2
50	16.9	7.5	3.3
5	10.8	4.8	2.1

(McMahon et al. 1993) The Columbia River Basin Interagency Invasive Species Response Plan: Zebra Mussels and other Dreissenid Species

mussels were present (CRB 2008).

Benthic Mats

Benthic mats are used to cover mussels and smother them, not allowing them to filter feed and reproduce. Research has shown that 2 weeks of covering yielded mortality rates from 14.8%-100%. Mats seem to be most effective in spot treatments during initial discovery (CRB 2008).

Chemical Treatment (Metallic Salts)

Metallic salts are successful at killing adult mussels. The successful eradication of Zebra mussels in Virginia was accomplished using Potassium salts. However concentrations of metallic salts must be high, for instance 88-288mg/l of Potassium salts is needed to cause mortality in mussels. 2-3 weeks of constant exposure is also needed to ensure 100% mortality. Though it may kill both Quagga and Zebra mussels it also kills native mussels but is non-toxic to fish (CRB 2008).

Chemical Treatment (Oxidizing Biocides)

These chemical treatments kill Quagga mussel by oxidizing the gill lamellae causing death. But Quagga and Zebra mussels can sense the presence of the chemical and can seal their shells for days. The mussels continue to test the water for toxins until forced to reopen to feed and respirate. Because of this defensive action, treatment takes 1-3 weeks. Curtains are often needed to isolate areas due to the toxicity to other organisms. Oxidizing chemicals include Bromine, Hydrogen Peroxide, and Chlorine (CRB 2008). Prechlorination is the most popular chemical control and eradication method for Quagga and Zebra mussels (Benson & Richerson 2008).

Chemical Treatment (Non-oxidizing Biocides)

The non-oxidizing biocides kill Quagga and Zebra mussels by entering the body of the mussels and attacking the cell walls. The mussels consequently lose the ability to sustain chemical balances and die. The biocides must be applied in high dosages which are very toxic most aquatic species including fish. In most cases the treated location must be detoxified. Examples of non-oxidizing biocides are Clam-Trol, Bulab, and Bayluscide (CRB 2008).

Bacterial Toxins

The most recent development in control and eradication methods is the use *Pseudomonas fluorescens* strain CL 145A. *Pseudomonas fluorescens* is a bacteria that is abundant in most environments. When large amounts of the bacteria are ingested by Quagga and Zebra mussels, the bacteria destroys their digestive system thus killing the mussel. Research has shown that dead bacteria is as useful as live bacteria. At this time the lethal dosage for Quagga and Zebra mussels does not cause any non-target mortality. Commercialization of the bacteria is expected in 2010 (CRB 2008).

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