THE QUAGGA MUSSEL (*DREISSENA ROSTRIFORMIS BUGENSIS*) INVASION OF THE WESTERN UNITED STATES

By

MITCHELL HAROLD WAGNER

A Thesis Submitted to The Honors College

In Partial Fulfillment of the Bachelors Degree
With Honors in

Environmental Science

THE UNIVERSITY OF ARIZONA

MAY 2016

Approved by:

____

Dr. Kevin Fitzsimmons
Department of Soils, Water and Environmental Science

Table of Contents

1. Abstract

First introduced in Western United States waters in 2007, the quagga mussel (*Dreissena rostriformis bugensis*) has rapidly spread throughout the Lower Colorado River and other bodies of water. Along the way, they have caused severe ecological and economical damage through ecosystem transformation and biofouling of water systems. To date, they have proved impossible to eradicate after colonization of a system. The best way to control quagga mussels is to prevent them from spreading to other waters. Once established, a combination of physical, chemical, and biological control methods need to be developed for that specific body of water. Continued research on best management practices and optimal facility designs are needed in order to control existing populations. Even though a solution for complete eradication of *D. Bugensis* has not been found to date, with public support and proper government funding, the effect of the quagga mussel in Western U.S. waters can be minimized.

2. Introduction

2.1 The Quagga Mussel

The quagga mussel *(D. bugensis)* is a freshwater bivalve first described by Nicolai Andrusov in 1897 (Velde 2007). Even though they are commonly called mussels, they are more closely related to clams, as they are both in the subclass Heterodonta. The term mussel is a non-scientific classification that refers generally to different families of bivalves. Quagga mussels are native to the Dnieper River system in Ukraine (Choi et al. 2013). In its native habitat, quagga mussels are found in river channels, estuaries, and lakes (Son 2007). The mussels attach themselves to hard substrates, such as rocks, using filaments called byssal threads. These threads are made up of proteins, which are synthesized when they have settled onto a substrate (Peyer et al. 2008)

Adult mussels range from one to three centimeters and can occur at densities of over a 1,000,000 per square meter (Ram et al. 2012). They are filter feeders that remove suspended particles from the water column, thus increasing water clarity and lowering densities of microalgeas and nutrient uptake rates (Wong et al. 2010). Even though adult Dreissenids are benthic, sessile invertebrates, they have the ability to greatly alter the ecosystem surrounding them. By removing phytoplankton, the lowest level of an aquatic food chain, they can completely alter a food web (Karatayev et al. 2015).

2.2 Life History

Before discussing the life history of the quagga mussel, it should be noted that much of the detailed research on Dreissenid life cycle (Ackerman et al. 1993; Nichols and Black; 1994) has been done on the closely related zebra mussel (*Dreissena polymorpha;* Pallas 1771). Figure 1 demonstrates the similarities and slight differences between both species. The two species are nearly indistinguishable in early larval development and they share the same development cycle (Nichols and Black 1994). The only notable difference in development is the size and thickness of shells at various life stages.

Like many other successful invasive species, Dreissenids have shown the ability to exhibit exponential growth (Lucy 2006). There are three main stages to the Dreissenid life cycle: larval/veliger, juvenile and adult. Figure 2 depicts a typical Dreissena life cycle. The larval/veligers have four stages; the trochophore, straight-hinged, umbonal, and pediveliger (Lucy 2006). The life history of the quagga mussel begins with external fertilization that occurs when gametes are released into the water column by male and female individuals, each of which is capable of releasing 30,000 gametes in a single reproduction event and over 1,000,000 in a year (Ackerman et al. 1993). Following the fertilization event, trochophore larvae develop. Trochophores are free swimming, and are not considered veligers until they develop the velum, which is a larval organ that is used for movement and feeding (Ackerman et al. 1993). After two to nine days, the trochopore begins secreting a D-shaped, or straight hinged, shell. This shell is unornamented and ranges from 90-120 μm (Black 1996). Seven to nine days after fertilization, the veliger begins secreting a more elaborate umbonal shell (Ackerman et. al 1993). The umbonal veliger is the last free-swimming stage of the Dreissenid life history, as it begins to develop into the pediveliger. This stage sees the development of more advanced organs like early gill structures, the foot, and the related byssal structure (Ackerman et al. 1993). The pediveliger uses the well-developed foot and byssal structure to swim and crawl around rocks. Sometime between 18 and 90 days after fertilization, the pediveliger will anchor itself to a hard substrate by secreting byssal threads, thus ending the veliger stage of the life cycle (Ackerman et al. 1993). All of these stages are microscopic and invisible to the naked eye.

Following settlement and the anchoring of byssal threads, the mussel undergoes metamorphosis. The primary changes during this stage include the loss of the velum, the development of the mouth and gills, and the excretion of an adult shell, all while going from a rounded, clam-like appearance to a more triangular, mussel-like form (Ackerman et al. 1993). The juvenile stage comes to an end when the mussel reaches sexual maturity. The adult mussel will continue to grow until it reaches a shell length of 1-3 centimeters.

2.3 Spread to and Through the United States

The first sighting of a Dreissenid in the United States came in 1986 when zebra mussels were spotted in Lake Erie. By 1988, they had spread all the way to Chicago's shores of Lake Michigan (Carlton 2008). It wasn't until August of 1991 that the quagga mussel was spotted in the Erie Canal and Lake Ontario (Mills et al. 1996). It is possible that quagga mussels were in U.S. waters prior to 1991 and had not been discovered due to their similar appearance to zebra mussels. It is believed that the Dreissenids were introduced to U.S. waters via ballast waters from ships travelling from the Black and Caspian Sea (Carlton 2008). Before the National Invasive Species Act (NISPA) of 1996, it was routine for ships to pump in ballast water at one port, and dump that water at another port. After the signing of NISPA, ships travelling from freshwater bodies are required to dump the port of origin's ballast water in the ocean, pump in ocean water to the ballasts, and dump the ocean ballast water in the final destination's port. The idea behind this is that marine species cannot survive in freshwater and vice versa, thus preventing the establishment of foreign species from ballast discharge. Regardless, the quagga mussel was introduced before the act was in place, and has continued to spread since.

The 100th Meridian Initiative was created after the arrival of Dreissenids in North America, with the goal to prevent the westward spread of quagga and zebra mussels that were taking over the Great Lakes. Their efforts focused on boater education and, in partnership with the U.S. Fish and Wildlife Service, boat inspections. These efforts were effective at preventing the westward spread until 2007, when quagga mussels were found in Lake Mead, Nevada (Wong and Gertsenberger 2011). It is believed that the mussels arrived from boats traveling from the Great Lakes that had not been properly sterilized before entering Western U.S. waters (Choi et al. 2013). When a watercraft leaves a body of water, residual water can still remain in bilges, wet and live wells, and engine cooling systems. A study done by Choi et al. 2013 revealed that *D. bugensis* veligers can survive in residual boat water for up to five days in the summer and 27 days in autumn. Figures 3 and 4 show Choi et al.'s results from their study. Veliger mortality reached 100% after 120 hours in the summer, and 648 hours in the autumn. The more developed a veliger was, the longer it was able to survive. For example, trochophores survived 384 hours, while the pedivelgers could survive for up to 648 hours. The Arizona Game and Fish Department recommends that day-use boaters quarantine their vessel for five days before putting it in a new water body. If a watercraft is moving locations in the autumn, there may be still be viable veligers in residual water if quarantined for only five days. This can lead to the spread of *D. bugensis* to a previously uninfected body of water.

After the initial sighting in 2007, populations seemingly exploded throughout the Lower Colorado River. By the end of the year, *D. bugensis* had been spotted in Lake Havasu, Lake Pleasant, the Willow Beach National Fish Hatchery, and the Central Arizona Project in Phoenix. By 2008, they had been spotted as far west as San Diego and by the end of 2010, quagga mussels had been spotted in essentially every major reservoir in the Lower Colorado River, from Lake Powell to the Imperial Dam. As of March 2016, *D. bugensis* had been found in six states west of the 100th meridian. Figure 5 depicts quagga mussel sightings in the Western United States as of April 2nd, 2016 (USGS 2016).

The rapid spread can be attributed to *D. bugensis'* life history. Quagga mussels have relatively short life spans and are able to reproduce early and often, which leads to nearly exponential growth in populations (Lucy 2006). When quaggas were spotted west of the continental divide, it was the first time that *D. bugensis* was found in an area containing no zebra mussels (Choi et al. 2013). This can most likely be attributed to the fact that quagga mussels have larger energy reserves than zebra mussels. This is due to their lower respiration rates and larger body size (Ram et al. 2011), which would enable *D. bugensis* to survive a journey from the Great Lakes to Lake Mead in smaller watercrafts.

2.4 Impacts

One of the largest problems associated with quagga mussels are their biofouling capabilities. Biofouling is the accumulation of organisms on a wetted, usually underwater, surface. Since the mussels can occur in large densities, they frequently clog underwater intake pipes and cooling systems of hydroelectric plants.

Removing the mussels is labor intensive and costly, and industrial entities lose money when they have to shut down their operations to clean cooling and emergency water systems. From 1989 to 2004, it was estimated that Dreissenid fouling of water intake and hydroelectric facilities along the Great Lakes cost $267 million (Connelly et al. 2007). Figure 6 shows the biofouling capability of mussels.

Quagga mussels are also having large ecological impacts. Each mussel can filter up to one liter of water a day (Oregon Sea Grant 2008). They draw water through their siphon into their mantle cavity, where particles for ingestion are selected (Baker et al. 2000). Recent research has revealed that quagga mussels selectively consume phytoplankton based on species, rather than size, and they eject the unwanted phytoplankton species back into the water column (Tang et al. 2014). The targeting of certain phytoplankton species is dramatically altering the bottom of the food web in lakes and reservoirs, as bodies of water are shifting to higher concentrations of phytoplankton such as *Microcystis* and other cyanobacteria (Vanderploeg 2013). Table 1 summarizes the results from Howell et al. 1996 work on monitoring the changes that Dreissenids cause on lake water chemistry. Howell et al. found that the mean suspended particle size changed from fine sand (125-200 μm) to silt (4-7 μm) after Dreissenid colonization. Further changes include; increased water clarity and lower chlorophyll α, calcium, and phosphorous levels, as well as a reduction in the number of native bivalves. The increased water clarity has allowed for the growth of nuisance algae at greater depths (Wong and Gertsenberger 2011). All of these changes have led to large sport fishery losses, resulting in damages estimated at four billion dollars within the first decade that

Dreissenids were introduced into the Great Lakes (Roberts 1990). More long-term research is needed in order to gain a greater understanding of all ecological impacts.

3. Methods

The information in this review style paper was obtained from a variety of sources. Academic publications were found using online scholarly search engines or through the University of Arizona Library systems. There was also a lot of "grey" literature that was pertinent to this paper. Grey literature is unpublished data and results obtained by government agencies. This information was found by searching through online government databases. Hearings and other proceedings relating to the topic were also incorporated in this document.

4. Discussion

4.1 Synthesis of Research

Once a body of water is infested with Dreissenids, it is virtually impossible to eradicate them. There has only been one documented case of a complete decontamination, and that was in an isolated quarry in Virginia (WRPANP 2010). The Virginia Department of Game and Inland Fisheries treated the 12-acre quarry with 174,000 gallons of potassium chloride, which resulted in 100% mortality of the existing zebra mussel population. However, this was an isolated and contained water body, and these results are not applicable to larger river, lake or reservoir systems. With current technologies, there is no known method to eradicate established Dreissenids from a complex water body, and often, total eradication is impossible. Rather, populations are managed, so that essential functions in hydropower and water delivery systems remain operational. Management is difficult and costly, as each body of water has its own unique water chemistry, geology, and hydrologic patterns, resulting in numerous different management plans for each system.

To date, the most effective control method has been prevention of establishment. Preventing mussels from contaminating a water body is often much less expensive than trying to manage them once they are established. Even though efforts were futile in the end, the 100th Meridian Initiative prevented the westward spread of Dreissenids for over a decade, which saved taxpayers hundreds of millions of dollars by not having to pay for management of infested waters. The main component of prevention is to educate the public on why and how they can prevent spreading mussels. Public support and education are the foundation of any large-scale management plan. Furthermore, the average boater is one of the greatest threats to spreading quagga mussels, as they have the ability to remove their boat from an infested lake and launch it in an unexposed water body within the same day. As was previously mentioned, it is believed that quagga mussels travelled from the Great Lakes to Lake Mead not in a large commercial vessel, but rather in a smaller, personal watercraft. With the public's support and knowledge about the issue, future translocation events like the one that occurred in 2007 can be prevented.

When quagga mussels were first spotted in the Western United States, Lake Mead became ground zero for the invasion. Millions of dollars of grant money were allocated for research into the mechanisms of the Dreissenid invasion in Lake Mead. Federal and state agencies began earmarking millions of dollars of their budgets in order to support this research (Wirkus 2008). Yet, as the spread continued down the Colorado River and across the West, the money allocated for research began to go towards control and maintenance costs (Wirkus 2008). As a result, the number of publications on quagga mussels has declined since 2010.

In addition to the lack of funding, another plausible explanation for the lack of research in recent years can be attributed to a lack of interest. When the quagga mussel invaded Lake Mead in 2007, it made national headlines and there was a large amount of public interest. Over the next few years, researching ways to manage and prevent the further spread of species was a hot topic for the scientific community and state agencies. Yet, as the spread continued and efforts to eradicate proved unsuccessful, interest in the invasion declined and the establishment of *D. bugensis* was accepted as problem that needed to be managed, rather than solved.

4.2 Ideal Integrated Pest Management (IPM) Plan

Nearly a decade after the first quagga mussel was spotted west of the Continental Divide, there has been a shift from researching and learning about the species, to how facilities can monitor and manage them. The following will outline an ideal IPM plan that can be implemented in different state agencies that manage water bodies. The IPM was developed by incorporating elements from action plans created by The United States Bureau of Reclamation, The Western Regional Panel on Aquatic Nuisance Species, The State of Michigan and the Arizona Game and Fish Department.

I. Prevention

The most effective way to manage *D. bugensis* is to prevent them from ever entering a body of water. Inspection stations should be set up at boat launches where an initial visual inspection of the boat will be performed. Inspectors should look for any adult mussels attached to the boat, specifically on the bottom, propeller and anchor areas. If there are no visual signs of attachment, the boat owner should then be asked to list every water body that they launched their boat in the past 30 days. If the boat has been in water with a known *D. bugensis* infestation, then the inspector will go over the appropriate decontamination procedure (Appendix A or B) and fill out an inspection document (Appendix C). The boater shall not be allowed to launch his/her boat until all necessary decontamination procedures are followed, and a fine may be assessed depending on which state the boater is in.

Another key component of prevention is education. Outreach programs should be established that aim to educate the public on the threat that quagga mussels pose to native waters. These programs can be run in classrooms, at boat shows, during summer camps, etc. Additionally, when boaters renew their registration, they can be required to take a brief course on quagga mussels and how to properly decontaminate their boat. This extra requirement will ensure that every boater is aware of *D. bugensis* and how to prevent their spread.

II. Monitoring

Monitoring is a critical component of the IPM as it can allow for the early detection of quagga mussels so that actions can be taken to prevent establishment. In the western United States, monitoring of lakes and reservoirs can occur yearround, as freezing of open water bodies is uncommon. The most obvious sign of *D. bugensis* is seeing the adult stage attached to a substrate underwater. Quagga mussels can colonize a large range of substrates, but they are most often found on rocks, docks, pipes, sunken debris, and areas where water flows in from an external source. There can be indirect signs of adult colonization, such as an increase in water clarity or decrease in dissolved calcium levels. The difficult aspect of monitoring is identifying the microscopic veligers. Clean Lakes INC. sells a veliger identification kit for about $150; the kit (Figure 7) includes planktonic net that is designed to catch the veligers and filter them into a sampling bucket. The samples can then be shipped to Clean Lakes INC., where they will analyze and determine if any *D. bugensis* specimens are present.

III. Physical Controls

One of the most practical ways to physically control quagga mussel populations is by mechanical removal. This can be as simple as having a SCUBA diver scrape off covered intake pipes or other surfaces that are critical to a water system's operation. However, this method is often one of the least cost effective, as it requires skilled labor. A more cost effective method of physical control is to apply a filter over the intake pipe, which prevents adult mussels from entering the system. However, veligers can still pass through and the filter routinely needs to be scraped free of debris. Some systems are incorporating automated, self-scraping grates and filters, but these require manual maintenance from time to time. A system located in an infested body of water should have scrapings performed on all external critical water components every few months, as to ensure that functionality of the system is never lost. Increasing the water pressure through pipes can clear internal water systems, but disposal of dislodged mussels needs to be considered.

IV. Chemical Controls

i. Coatings

Coatings should be considered when designing new systems, as they have shown promise in preventing settling of adult mussels on infrastructure (USBR 2015). Anti-fouling coatings are applied to pipes, intakes, and other surfaces during construction. These coatings leach toxic biocides, such as cuprous oxides, into the water that deter attachment of *D. bugensis*. There are also silicone-based coatings that are meant to be too slippery for the mussels to attach to, thus preventing the settling of veligers. If coatings are to be used in a system, they need to be reapplied every two to three years in order to maintain their effectiveness. Copper metals are also effective at deterring the attachment of adult mussels and do not need to maintained like applied coatings (USBR 2012).

ii. Chlorine

One of the most widely used chemical treatments to prevent biofouling is through the use of chlorine. Water containing 0.5 to 3.0 mg/L of gaseous chlorine has the ability to result in 100% mortality of adult Dreissenids (USBR 2012). Typically, the gaseous chlorine is added via a chemical feed line at water intakes. The chlorinated water then proceeds into the facility's system, where it kills settled mussels. If implementing chlorine use, proper permits need to be obtained in order to discharge the chlorinated water. Furthermore, the transport and handling of chlorine can be hazardous, and if released improperly into the environment, it can have negative effects in ecosystems (Matthews et al 2012).

iii. Potassium Chloride (BioBullet)

Microencapsulated potassium chloride (KCl) compounds known as BioBullets, have been developed as an alternative to chlorination. Typically, when Dreissenids are exposed to toxins such as KCl, they close up and stop filter feeding, rendering the toxin ineffective. The BioBullet is designed to selectively affect Dreissenids and the microencapsulation prevents them from detecting the toxin and closing up (Matthews et al 2012). Aldridge et al. 2006 produced results claiming that BioBullets only effect target Dreissenids and do not harm native bivalves. However, tests have revealed that BioBullets do not produce 100% mortality, even after multiple dosing's (Matthews et al. 2012). As a result, this method is intended to control populations in larger bodies of water, rather than eradicate them in essential closed water systems.

V. Biological

Animals such as the common carp, channel catfish, diving ducks, muskrats and crayfish have all been observed eating Dreissenids (GISD 2009). However, given the sheer number of *D. Bugensis* that can occur, it is difficult for larger predators to keep populations in check. As a result, biological controls alone cannot be counted on to mange quagga mussel populations. A much smaller biological control has been proposed, as the bacteria *Pseudomonas fluorescens* has been observed to result in over 90% mortality in quagga mussel populations (Molloy

2008). However, much more testing needs to be done on the effects of native organisms before water bodies begin treatment with the bacteria.

5. Conclusion

To date, a "silver bullet" has not been developed for the total eradication of *D. Bugensis*. As a result, the most effective method of controlling populations is to prevent them from ever establishing in a body of water. If quagga mussels do establish in a body of water, a wide variety of tactics will need to be employed to manage them and ensure the continuing functionality of all water systems. Other invasive species like mitten crabs, hydrilla, and watermilfoil have threatened freshwater environments and water delivery systems, but to date, these nuisance species have been managed to the point where water delivery has not been compromised. Continued research and funding will be needed in order to say the same for quagga mussels. The presence of *D. Bugensis* will alter the way that future facilities are designed and operated in the Western United States. For the foreseeable future, quagga mussels will remain in Western waters, but with diligent management, public support and proper funding, their economic and environmental impacts can be minimized.

6. Figures

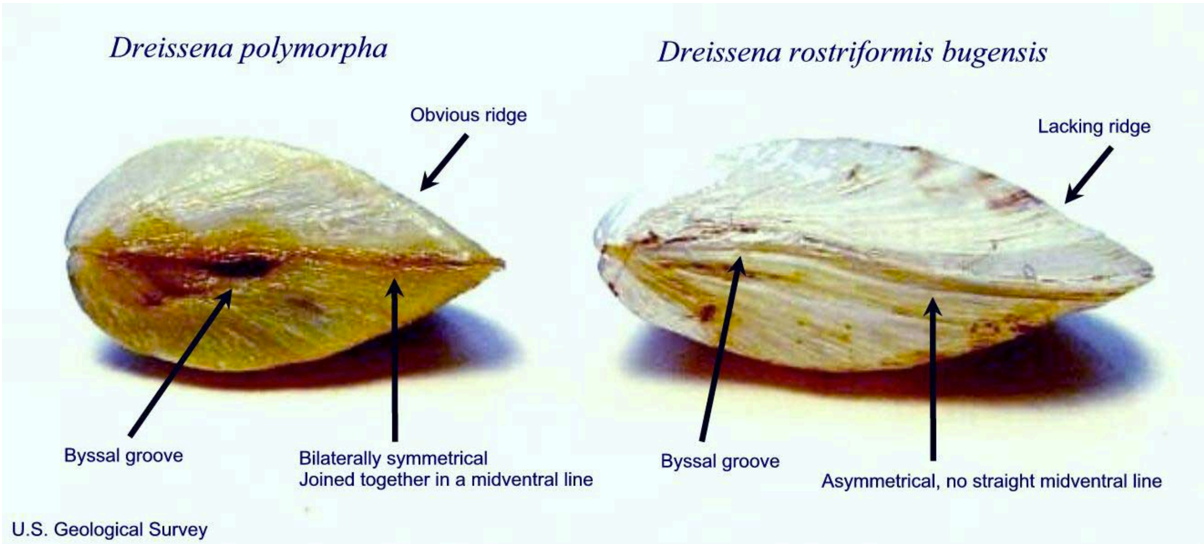

Figure 1: The similarities and differences between *Dreissena polymorpha* and *Dreissena rostriformis bugensis.* Credit USGS

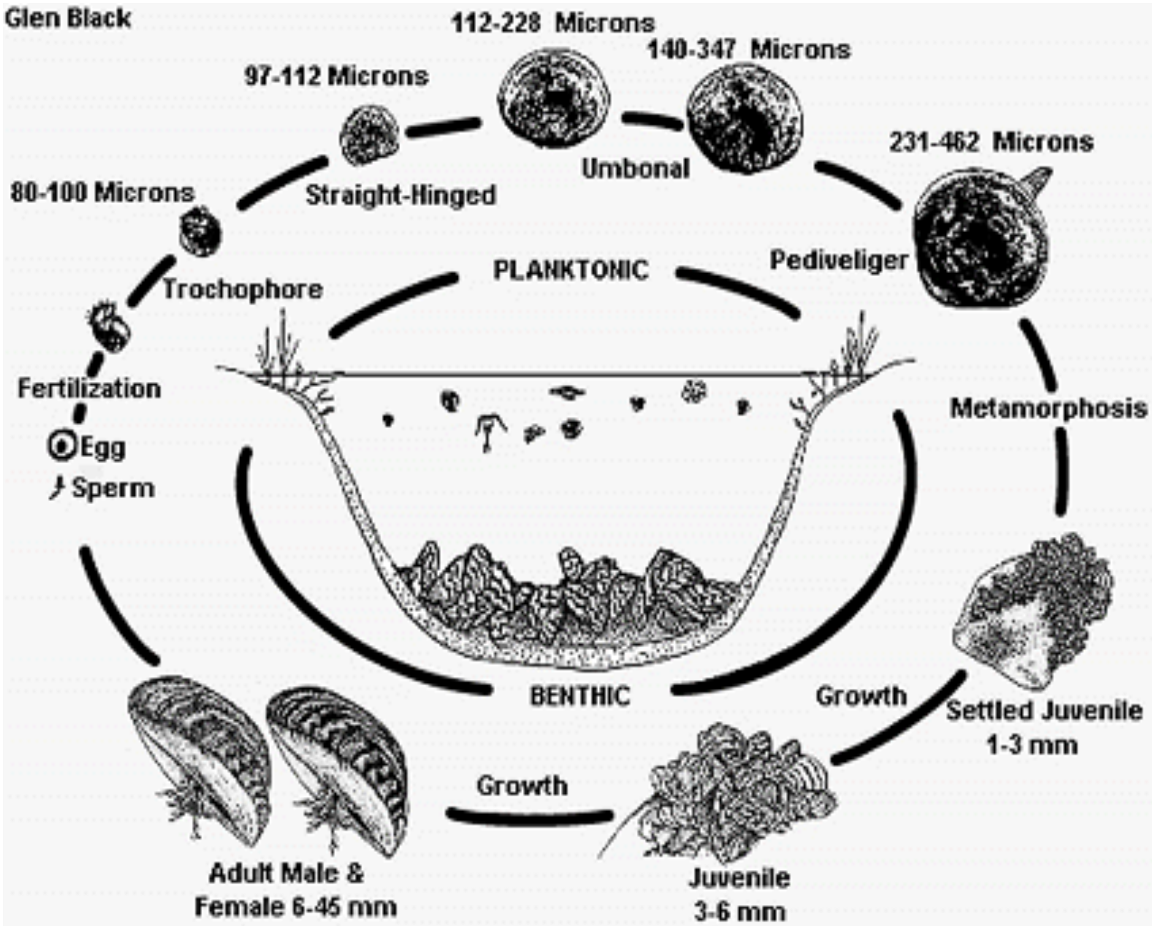

Figure 2: A typical life cycle of Dreissenids. Note the microscopic veliger stage, and how after metamorphism, the mussel settles and become visible to the human eye. Credit: Glen Black, 1996.

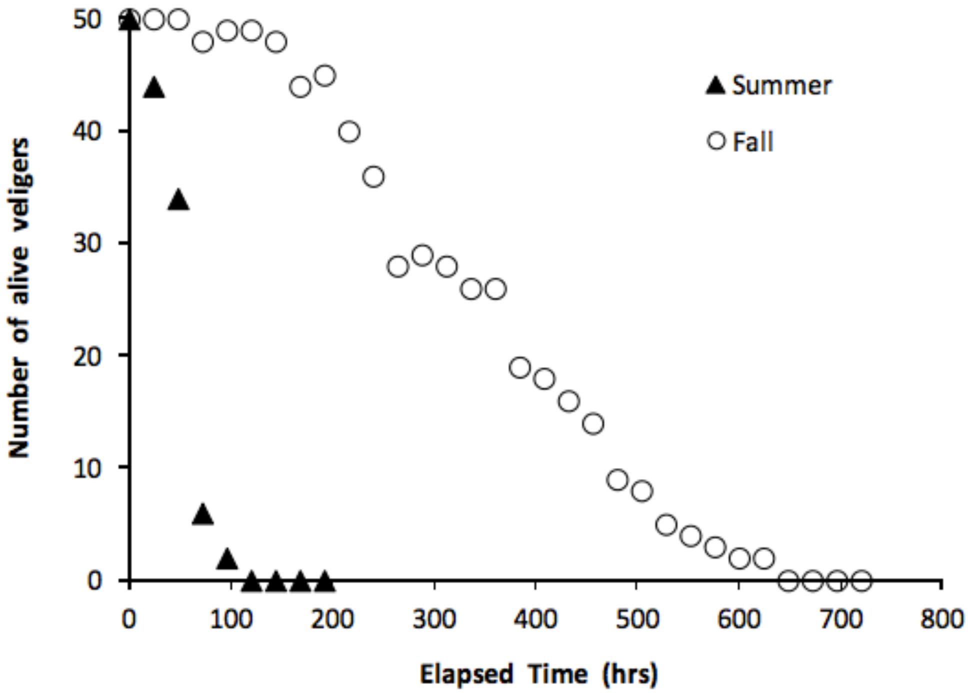

Figure 3: Surviving quagga mussel veligers versus exposure time in summer and autumn temperature exposures. Choi et al. 2013

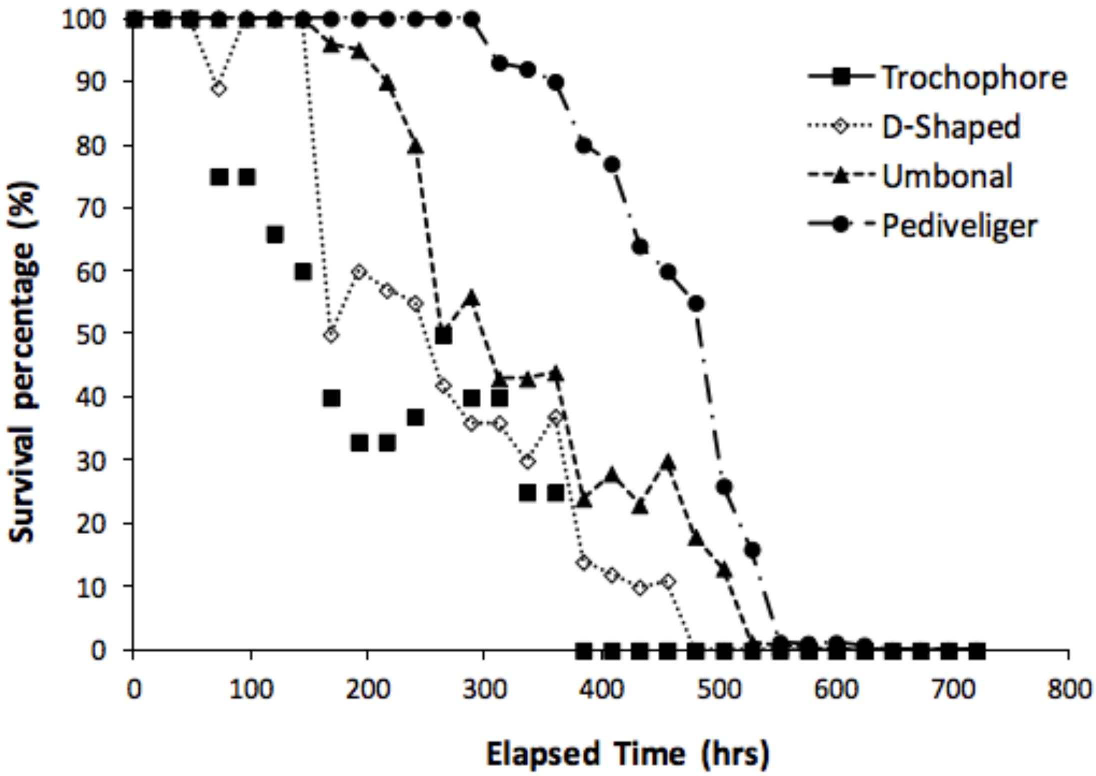

Figure 4: Survival rates of different quagga mussel veliger stages during autumn temperatures. Choi et al. 2013

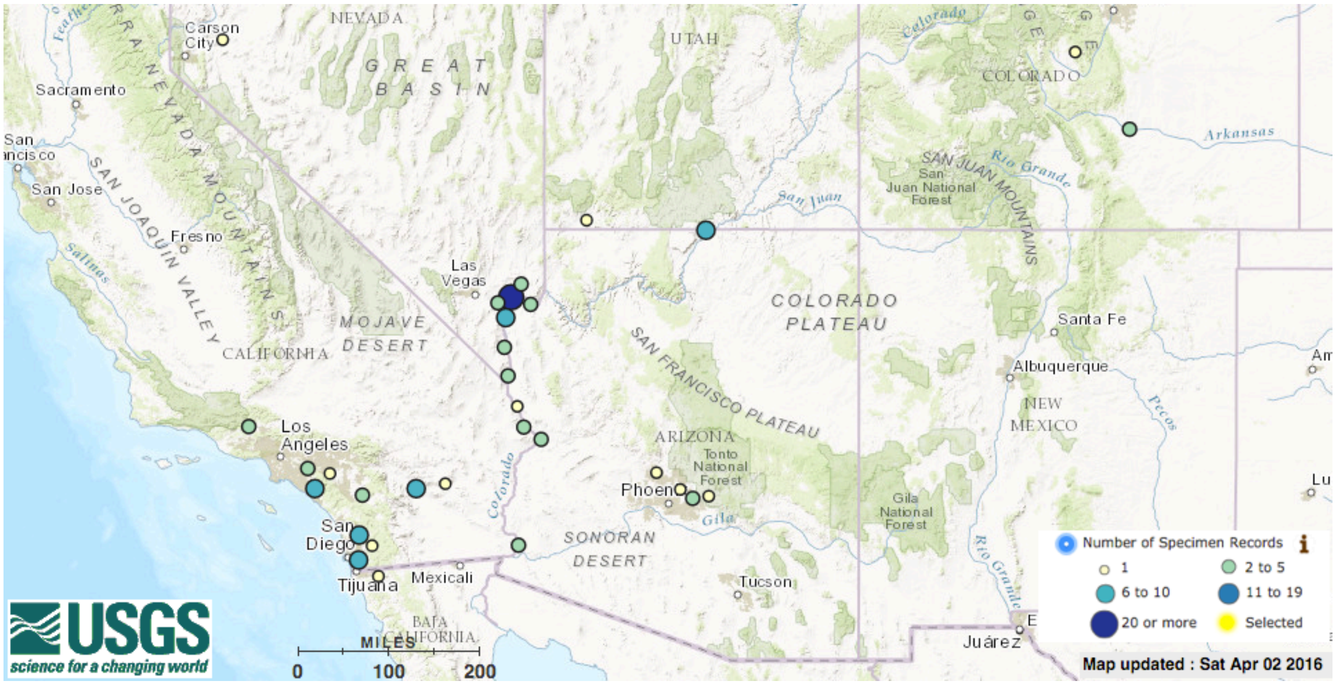

Figure 5: USGS map of Quagga mussel sightings as of April 2nd, 2016

Figure 6: Dreissenid biofouling capability. Credit: Ruth Lake Community Services District

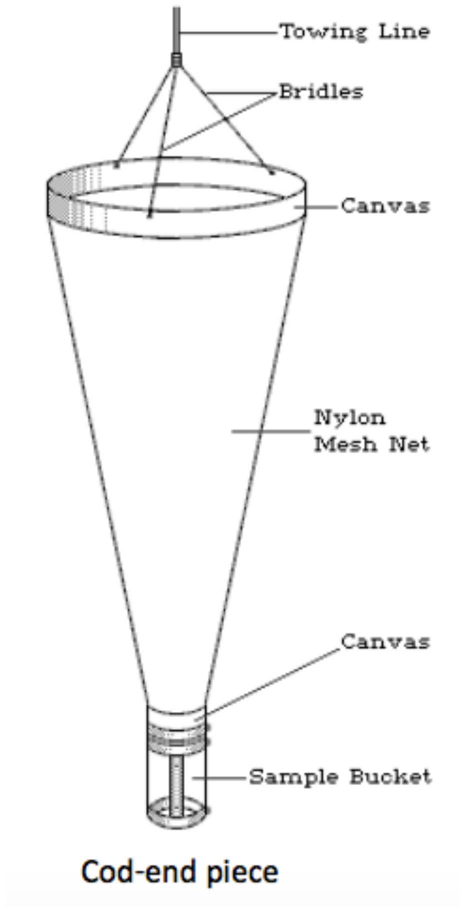

Figure 7: A quagga mussel veliger sampling kit. Credit Clean Lakes INC.

Table 1 (Howell et al. 1996): Annual ranges of mean concentrations of water quality variables in Eastern Lake Erie. The numbers in parentheses indicate number of sampling dates.

Water Quality Variable	1988		1989		1990		1991		1992	
Total Phosphorus (µg/L)	15	(1)	7–27	(7)	2–15	(3)	5–12	(3)	5–9	(3)
Total Kjeldahl Nitrogen (mg/L)	0.26	(1)	0.24–0.28	(7)	0.23–0.32	(3)	0.18–0.26	(3)	0.22–0.23	(3)
Suspended solids (mg/L)	8.4	(1)	1.1–23.8	(7)	1.3–6.6	(3)	1.0–3.2	(3)	0.8–2.4	(3)
Dissolved Organic Carbon (mg/L)	1.9	(1)	1.9–3.0	(7)	2.0–2.2	(3)	2.0–2.1	(3)	1.9–2.2	(3)
Chloride (mg/L)	14.6	(1)	14.3–15.5	(7)	14.8–17.4	(3)	14.9–15.8	(3)	14.9–15.4	(3)
Calcium (mg/L)	38.5	(1)	35.8–38.9	(7)	35.3–36.3	(3)	34.7–35.6	(3)	32.8–34.2	(3)
Conductivity* (µmho/cm)	283	(1)	280–288	(7)	273–277	(3)	273–278	(3)	272–276	(3)
pH	8.33	(1)	8.25–8.34	(7)	8.14–8.24	(3)	8.19–8.31	(3)	8.14–8.36	(3)

*corrected to 25°C

7. Appendices

Appendix A: Decontamination Procedures for Day Use Boaters

Adapted from AZGFD's Don't Move a Mussel Program and Choi et al. 2013

1. When the boat is removed from water, perform a visual inspection of entire boat and remove any clinging debris. This can include mud, plants and/or animals.
2. Remove the plug and drain water from the live-well, bait-well, bilge, and the engine and its cooling systems.
3. Hose down boat with a pressure washer using 140 °F water.
4. Allow the boat to dry completely for at least **5 consecutive days**.
5. Replace the bilge drain plug and disinfect surfaces of boat with at least one gallon of vinegar. Remove the plug again to drain and rinse the boat one final time before launching again.

Appendix B: Decontamination Procedures for Long-Term Moored Boats

Adapted from AZGFD's Don't Move a Mussel Program and Choi et al. 2013

1. When the boat is removed from water, perform a visual inspection of entire boat and remove any clinging debris. This can include mud, plants and/or animals.
2. Remove the plug and drain water from the live-well, bait-well, bilge, and the engine and its cooling systems.
3. Physically remove any attached adult mussels from all areas of boat, including the hull fittings, motor, propellers, anchor, etc.
4. Hose down boat with a pressure washer using 140 °F water.
5. Flush the engine and cooling system with 140 °F water for at least 30 seconds.
6. May-September: Ensure that the boat is completely dry and remains out of water for at least **7 consecutive days**.

   October-April: Ensure that the boat is completely dry and remains out of water for at least **27 consecutive days**.
7. Replace the bilge drain plug and disinfect surfaces of boat with at least one gallon of vinegar. Remove the plug again to drain and rinse the boat one final time before launching again.

Appendix C: Example AZGFD Inspection Document

Arizona Game and Fish Department

Aquatic Invasive Species Boat Inspection Report (AISBIR)

Per Watercraft Inspection Protocols Recommended by "Western Regional Panel on Aquatic Invasive Species"

Date:	Time:	Location:	Watercraft Inspected By:

VesselType:______________________________	**Owner**:____
Make:__________________________________	Address:____
Model:______________________________ Size:	City:____________________________ State:__________ Zip:
State Registration # {or USCG Documented #}: ______________________________________	**Phone**:____
Vessel Name: ____________________________	

Commercial Transport Company or Name of Person transporting vessel:	**Transporter/Owner Contact Number:**

Date Removed from Water:	**How Long in Water:**	**Lake or Waterbody:**
Weather Conditions Since Removed From Water (check all that apply): Wet Moist Humid Dry Hot Cold		
Final or Ultimate Launch Location/Destination (Lake name & State):		
Destination Jurisdiction(s), if known:	Date Notified:	
How Long Will Boat Stay out of Water in Current Location (Desiccation Period):		
Anticipated Travel Date:	**Destination ETA:**	

CLOSE INSPECTION: (Before Decontamination)

IDENTIFIED MUSSEL LOCATIONS	**Visible AIS/ Mussels** (check if Yes)	**Visible Vegetation/ Algae** (check if Yes)	**Comments**
Hull, Engine, Outdrive, Propeller Shaft, Thrusters			
Trim Tabs, Pitot Tubes, Transducers, Rudders, etc.			
Generator			
Bilge, Through Hull Fitting			
Bait and/or Live Wells			
Anchor Rope/Chain and locker			
Trailer			

ARE MUSSELS PRESENT?? **Yes = Decontamination Required Before Transport**

Explain Decontamination Plan:

Where: By Whom (Name):

How:

I affirm that the above information is true and complete. I understand that this fully completed inspection form does not certify that the watercraft listed herein has been fully decontaminated; only that it was self-inspected by the owner/transporter for presence/absence of visible aquatic invasive species (AIS), including invasive mussels (DO 1). I understand the vessel may not be transported from the AIS listed water vicinity (DO 2) or other location as authorized by the Department until such time as vessel has been properly cleaned, drained and dried for all AIS, per current AGFD Director's Orders (DO 3). I further understand that it is unlawful to transport Arizona listed AIS (e.g., quagga mussels) under A.R.S §17-309 and §17-255.02, and Arizona Administrative Code Rules R12-4-406 and R12-4-1102.

Signed:____ Date:____________________________

Printed Name:____

Legal Standing in this Matter: **Boat Owner** ______ **Transporter**_______ **Other**___________

REQUIRED BEFORE TRANSPORT to another water – Please fax (623-236-7265) or scan/email (AIScomments@azgfd.gov) this completed form to AGFD

AGFD INCIDENT NUMBER:	Date Released (no Visible adult mussels standard attained):

FOLE_FORM 2137_02/07/2014 page 1 of 2

8. References

Ackerman JD., Sim B, Nichols SJ and Claudi, R (1994). A review of the early life history of zebra mussels (*Dreissena polymorpha*): comparisons with marine bivalves. Can. J. Zool. (72): 1169- 1179.

Aldridge DC, Elliott P and Moggridge D (2006) Microencapsulated BioBullets for the control of biofouling zebra mussels. Environmental Science and Technology 40:975-979

Baker SM, Levinton JS, Ward JE (2000) Particle Transport in the zebra mussel *Dreissena polymorpha*. Biol. Bull., (199): 116-125

Carlton JT (2008). The Zebra Mussel *Dreissena polymorpha* Found in North America in 1986 and 1987. Journal of Great Lakes Research, 34(4):770-773. http://dx.doi.org/10.3394/0380-1330-34.4.770

Choi WJ, Gertsenberger S, McMahon RF, and Wong WH (2013) Estimating survival rates of quagga mussel (*Dreissena rostriformis bugensis)* veliger larvae under summer and autumn temperature regimes in residual water of trailered watercraft at Lake Mead, USA. *Management of Biological Invasions* (4): 61-69, doi: http://dx.doi.org/10.3391/mbi.2013.4.1.08

Connelly NA, O'Neill Jr. CR, Knuth BA, Brown TL (2007) Economic Impacts of Zebra Mussels on Drinking Water Treatment and Electric Power Generation Facilities. *Environmental Management* (40): 105-112, DOI 10.1007/s00267-006-0296-5

GISD (Global Invasive Species Database). 2009. Dreissena polymorpha. Online at http://www.issg.org/database/species/ecology.asp?si=50.

Lucy F (2006) Early life stages of *Dreissena polymorpha* (zebra mussel): the importance of long-term datasets in invasion ecology. *Aquatic Invasions* (1):3 171-182, DOI 10.3391/ai.2006.1.3.12

Matthews G, van der Velde G, bij de Vaate A and Lueven RSEW (2012) Key factors for spread, impact and management for Quagga mussels in the Netherlands. Final technical report. Radboud University Nijmegen. https://www.researchgate.net/profile/Abraham_Bij_De_Vaate2/publication/254883031_Key_factors_for_spread_impacts_and_management_of_quagga_mussels_in_the_netherlands/links/00b7d5265797e65e56000000.pdf

Mills EL, Rosenberg G, Spidle AP, Ludyanskiy M, Pligin Y, May B (1996) A Review of the Biology and Ecology of the Quagga Mussel (Dreissena bugensis), a Second Species of Freshwater Dreissenid Introduced to North America. *American Zoology* (36): 271-286

Molloy DP (2008) Environmentally safe control of zebra mussel fouling. Final technical report. New York State Education Department, USA. www.netl.doe.gov/technologies/coalpower/ewr/pubs/NT41909_NY%20Dept%20of%20Educ_Final%20Re port.pdf.

Nichols SJ and Black MG (1994). . Identification of larvae: the zebra mussel (*Dreissena polymorpha*), quagga mussel (*Dreissena rosterformis bugensis*), and Asian clam (*Corbicula jlumineu*). Can. J. Zool. (72): 406- 4 17.

Oregon Sea Grant (2008) Aquatic Invasions: A Menace to the West. Unpublished. http://seagrant.oregonstate.edu/sites/seagrant.oregonstate.edu/files/invasive-species/toolkit/zebra-quagga-_mussels.pdf

Peyer SM, McCarthy AJ, Lee CE (2008)Zebra Mussels anchor byssal threads faster and tighter than quagga mussels. The Journal of Experiment Biology (212): 2027-2036, doi:10.1242/jeb.028688

Ram, J.L., Karim, A.S., Acharya, P., Jagtap, P., Purohit, S. and Kashian, D.R. (2011). Reproduction and genetic detection of veligers in changing Dreissena populations in the Great Lakes. Ecosphere (2): 1-16.

Roberts L (1990) Zebra mussel invasion threatens U.S. waters. *Science* (249): 1370-1372, http://dx.doi.org/10.1126/science.249.4975.1370

Son MO (2007) Native range of the zebra mussel and quagga mussel and new data on their invasions within the Ponto-Caspian Region. *Aquatic Invasions* (2) 174-184

Tang H, Vanderploeg HA, Johengen TH, Liebig JR (2014) Quagga Mussel (*Dreissena rostriformis bugensis*) selective feeding of phytoplankton in Saginaw Bay. Journal of Great Lakes Research (40): 83-94, doi:10.1016/j.jglr.2013.11.011

United States Bureau of Reclamation (2012) Coatings for Mussel Control- Three Years of Laboratory and Field Testing. Technical Memorandum No. MERL-2012-11. Accessed 4/9/2015 <https://www.usbr.gov/mussels/research/docs/20120821-MusselCoatings.pdf>

United States Bureau of Reclamation (2015) Antifouling coatings for invasive mussel control. USBR Research and Development Office. Accessed 4/9/2015 <http://www.usbr.gov/research/projects/detail.cfm?id=7095>

Vanderploeg HA, Wilson AE, Johengen TH, Dyble J, and Sarnelle O (2013) Role of selective grazing by dreissenid mussels in promoting toxic *Microcystis* blooms and other changes in phytoplankton composition in the Great Lakes. Quagga and Zebra Mussels: Biology, Impacts and Control (2nd edition), CRC Press, Boca Raton, FL (2013) pp. 509-523

Velde GVD, Platvoet D (2007) Quagga mussels Dreissena rostriformis bugensis (Andrusov, 1897) in the Main River (Germany). Aquatic Invasions 2: 261-264, doi: http://dx.doi.org/10.3391/ai.2007.2.3.11

Western Regional Panel on Aquatic Nuisance Species (2010) Quagga-Zebra Mussel Action Plan for Western U.S. Waters. Submitted to the Aquatic Nuisance Species Task Force. Accessed 4/9/16 < http://www.anstaskforce.gov/QZAP/QZAP_FINAL_Feb2010.pdf>

Wirkus K (2008) Impact of Invasive Quagga Mussels. Statement by the Bureau of Reclamation Before the Committee on Natural Resources Subcommittee on Water and Power United States House of Representatives. Accessed 4/9/2016 < https://www.doi.gov/ocl/hearings/110/InvasiveQuaggaMussels_062408>

Wong WH and Gerstenberger SL (2011) Quagga Mussels in the Western United States: Monitoring and Management. *Aquatic Invasions* (6): 125-129, doi:10.3391/ai.2011.6.2.01