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Managing Water in the West

Summary of Laboratory and Field Experiments to Evaluate Predation of Quagga Mussel by Redear Sunfish and Bluegill

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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Quagga mussels, *Dreissena bugensis,* from Eurasia are widespread in the Colorado River drainage and associated waterworks, and are impacting state and federal water delivery operations. One potential mussel suppression agent is predation by redear sunfish, *Lepomis microlophus*. In aquaria experiments, 85.7 percent of juvenile and adult redear sunfish, *Lepomis microlophus*, and bluegill, *L. macrochirus*, were found to consume quagga mussels. Predated mussels were crushed and shell material was regurgitated and defecated. Mean mussel size consumed was positively correlated with fish size ($r=0.7$, $P=0.000$). In 21 field enclosure experiments, redear sunfish significantly reduced areal mussel density ($P = 0.0193$, Wilcoxon Rank Sum Test) by as much as 25.3 percent. However, this decrease was not observed in 6 of 13 fish enclosures which suggests that redear sunfish may consume other prey if available. Mussel density did not decline in enclosures without fish (<1 percent) and new mussel settlement was minimal. These experiments suggest that redear sunfish, and possibly other fish species, may help to control but not eliminate quagga mussel in areas where the two species co-occur.

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Executive Summary

Quagga mussels, *Dreissena bugensis,* from Eurasia are widespread in the Colorado River drainage and associated waterworks, and are impacting state and federal water delivery operations. One potential mussel suppression agent is predation by redear sunfish, *Lepomis microlophus*. Redear sunfish, a molluscivore native to the southeastern United States, occurs in portions of the lower Colorado River. In aquaria experiments, 85.7 percent of juvenile and adult redear sunfish and bluegill, *L. macrochirus*, were found to consume quagga mussels. Predated mussels were crushed and shell material was regurgitated and defecated. Mean mussel size consumed was positively correlated with fish size ($r=0.7$, $P=0.001$). In 21 field enclosure experiments, redear sunfish significantly reduced areal mussel density ($P = 0.0193$, Wilcoxon Rank Sum Test) by as much as 25.3 percent. However, this decrease was not observed in 6 of 13 fish enclosures which suggests that redear sunfish may consume other prey if available. Mussel density did not decline in enclosures without fish (<1 percent) and new mussel settlement was minimal. These experiments suggest that redear sunfish, and possibly other fish species, may help to control but not eliminate quagga mussel in areas where the two species co-occur.

Introduction

Quagga mussels (*Dreissena bugensis)* are exotic freshwater bivalves (Mollusca, Dreissenidae) that were introduced to the United States in the mid-1980's through ballast water discharge (Claudi and Mackie 1994; Mills et al. 1993, 1996; Ram and McMahon 1996). They are native to the southern Bug/Dnieper River delta (north Black Sea, Ukraine; Rosenberg and Ludyanskiy 1994; Son 2007) and were identified in Lake Ontario/Erie Canal in 1989 (May and Marsden 1992; Mills et al. 1993, 1996; Spidle et al. 1994). Quagga mussels have spread through much of the Great Lakes and were discovered in the western United States in Lake Mead in early 2007. Since then, quagga mussels have spread downstream through the lower Colorado River and associated canal, pumping, and power generation facilities. Zebra mussels (*Dreissena polymorpha*), another exotic freshwater bivalve (Mollusca, Dreissenidae) from Eastern Europe, has spread more quickly through the eastern United States but remains uncommon in the west (Benson 2011).

Zebra and quagga mussels have both benthic and planktonic aspects to their life history. Larvae (veligers) are free-swimming and may disperse through the water body. Juveniles and adults (post-veligers) settle and attach to most hard and soft surfaces using byssal threads, forming thick dense mats. These mussels can also detach and move using their foot like other freshwater bivalves (Toomey et al. 2002). Zebra mussels attain adult size quickly (>8mm) and both species may become reproductive their first year (Mackie 1993; Mackie and Schlosser 1996). Quagga and zebra mussels have somewhat different environmental tolerances (Mackie and Schloesser 1996; Spidle et al. 1994; Stoeckmann 2003) and historical distributions but both species are undergoing rapid range expansion through Europe and the United States (Orlova et al. 2005; Son 2007).

Establishment of zebra and quagga mussel in the United States has and will continue to have far-reaching negative economic and ecologic impacts (MacIssac 1996; Kennedy 2007; Strayer 2009; Western Regional Panel on Aquatic Nuisance Species 2009). Mussel infestations clog water intake and conveyance structures thereby reducing water delivery, pumping, and hydropower capabilities (Claudi and Mackie 1994; MacIssac 1996). Additionally, quagga and zebra mussels filter substantial amounts of water (Miller et al. 1992; Strayer 1999; Claudi and Mackie 1994) which negatively alters the food web of infested waters, in part by increasing water clarity (MacIssac 1996; Snyder et al. 1997). They also generate and potentially concentrate toxic waste that may pass up the food chain. Possible dreissenid mussel control measures include chlorination (and other chemicals), oxygen deprivation, thermal, electrical, sonic and pressure shock, desiccation, antifouling coatings, toxic bacteria, and predation. The objective of this study was to determine if fish predation on quagga mussels could help reduce mussel colonization in the lower Colorado River using replicated laboratory and field experiments. Redear sunfish, *Lepomis microlophus*, were selected for study because they are known molluscivores in southeastern United States (Lee et al.

1980), co-occur with quagga mussels in some areas (e.g., Lake Havasu), and were captured in upper Lake Havasu soon after the mussel invasion with quagga mussels in their stomachs (J. Lantow, Bureau of Reclamation). Bluegills, *L. macrochirus*, were included in the laboratory experiments because they co-occur with redear sunfish and quagga mussel in some areas in the lower Colorado River.

Methods

Phase I. Laboratory Experiments
Redear sunfish and bluegill were collected from upper Lake Havasu, Colorado River in June 2009 and 2010 and transported to Reclamation's Boulder City, Nevada Fish Lab. Fish were held in dechlorinated flow-through water (19.4 - 25.6 ^{o}C [67 - 78 ^{o}F]) and fed earthworms once daily. Fish were kept off feed for 24 h prior to an experiment. Quagga mussels (from the Colorado River and the Willow Beach National Fish Hatchery, U.S. Fish and Wildlife Service) were brought into the lab 48 h prior to use.

For each experiment, a group of 20 mussels were measured (length and height to the nearest mm) and counted into 10 or 20 gallon aquarium so that each tank contained a similar size range of available mussels (Figure 1). A single fish was added after 24 h during which the mussels had time to attach to the aquarium sides/bottom (unattached or dead mussels were removed before the start of each experiment and measured; larger fish were tested in the larger aquaria). Each aquarium was surrounded in black plastic so that there was no interference from neighboring tanks, or people. Artificial lighting was reduced during the day (nearby windows provided ambient lighting). Aquaria were maintained on aerated, dechlorinated, flow-through water for 48 h. At the end of each experiment, the fish was removed from the tank, anesthetized (50-ppm Tricaine Methanesulfonate) and measured (total length, TL). Digestive tracts of some fish were examined for presence of whole or crushed mussels. Remaining mussels from each aquarium were counted and measured, and mussel consumption was determined.

Stomachs of all potential molluscivore fish species occurring in lakes Havasu and Mohave, lower Colorado River, were examined for presence of juvenile/adult quagga mussels in spring 2010 in association with ongoing field studies by the Lower Colorado River Multi-Species Conservation Program.

Phase II. Field Enclosure Experiments
In 2012 and 2013, field enclosure experiments were conducted in which 1 - 2 redear sunfish were confined with quagga mussel colonized bricks in net enclosures for 2 - 4 months. Nine enclosures were labelled and deployed in a cove just upstream of Bureau of Land Management Partner's Point, Lake Havasu, Arizona (Figure 2). Net pens were 2m (6.5 ft) wide X 3m (9.8 ft) high with 6.3 mm (¼ in) mesh (Figure 3). The top had a zippered opening for access and a nylon canvas shade cloth provided some cover (Figure 4). Three-hole bricks were

suspended off Parker Dam the previous year to allow for quagga mussel colonization. Bricks were transported to the study site at the beginning of each experiment, cleaned of mussels on all but one flat and one side surface (including the three holes), and two bricks were suspended in each net pen from a center rope (one brick was suspended closer to the bottom of the enclosure and the other was nearer the surface). Four net pens were used to confine redear sunfish with mussel colonized bricks, and three net pens were used to hold mussel colonized bricks only. A blank brick was suspended in the 8th enclosure to determine ongoing mussel colonization in the study sight each year. Extra fish were held in the ninth enclosure with mussel colonized bricks for use when replacement fish were needed.

Distribution of mussels on the brick surfaces were photographed before, during, and at the end of the experiments, and these images were analyzed for percent mussel coverage (i.e., areal density) using image analysis software. Mussels that had moved into the holes in the bricks were excluded from the image analyses. We also tried counting mussels on the brick surfaces but this was very time consuming, and the results were similar to those in image analyses. Thus, we used image analysis.

Changes in mussel density between the beginning and end for of each brick surface was determined, and averaged for each enclosure. In some cases average mussel density at the end of an experiment was negative as either the distribution of mussels or size of shell increased over time. The nonparametric Wilcoxon Rank Sum Test for two independent samples was used to test for differences in mussel density between treatment (fish present, n=13) and control (fish absent, n=8) replicate enclosures because the percent data were not normally distributed. A subsample of mussel lengths was measured at study completion to obtain a size range. Redear sunfish captured by electrofishing and trammel netting during other ongoing fisheries studies in Lake Havasu were used. Fish were only measured at study completion and stomachs were not examined.

Results

Phase 1: Laboratory Experiments

A total of 35 redear sunfish (N = 28, 123 - 322 mm TL) and bluegill (N = 7, 124 - 214 mm TL) predation experiments with quagga mussels were conducted in the laboratory summer/fall 2009 and 2010. Most fish (85.7 percent) consumed quagga mussels (89.3 percent of redear sunfish and 71.4 percent of bluegill). Consumed quagga mussels averaged 12.4 mm length (3.0 - 26.8 mm) and 7.4 mm height (2.2 - 16.2 mm). The largest mussel offered was 28.3 mm in length and 16.1 mm height. Mean mussel size selected was highly correlated with fish size ($r = 0.7$, $P = 0.001$; Figure 5). Ingested mussels were mostly crushed and shell pieces regurgitated and defecated by the redear sunfish. Conversely, ingested mussels were not crushed by bluegill, rather defecated whole.

A total of 110 fish stomachs comprising 10 species were examined (Table 1). Of these, four species, redear sunfish, bluegill, channel catfish, *Ictalurus punctatus*, and common carp, *Cyprinus carpio*, had quagga mussels or shell fragments in their stomachs.

Phase 2: Field Enclosure Experiments
A total of 18 fish enclosure and 8 control (no fish) experiments were conducted. Of the 18 fish experiments, mussel coverage in five enclosures was not evaluated because the fish died during the experiments. In some instances, replacement fish and replacement bricks were added to net pens to restart an experiment or to maintain at least one live fish per cage. Redear sunfish that survived to study completion averaged 280.3 mm TL and 488.2 gm (235 - 348 mm TL, 241 - 1,115 gm; Figure 6).

Changes in mussel density averaged < 1 percent (0 – 0.6 percent) in non-fish and 7.9 percent (0 - 25.3 percent) in the fish enclosures. Mussel densities were significantly reduced in the fish enclosures compared to non-fish enclosures ($P = 0.0193$; e.g., Figure 7, 1A and 1B). However, of the 13 fish enclosure replicates, mussel densities decreased < 1 percent in 6 enclosures (e.g., Figure 7, 2A and 2B). Mussel densities in some control and fish enclosures increased over time presumably due to mussel shell growth and/or redistribution (e.g., Figure 7, 3A and 3B). Less than 10 quagga mussels colonized the blank brick surfaces in both years which suggests that quagga mussels were not colonizing the bricks during the experiments (Figure 7, 4A and 4B).

Water temperatures averaged 15.3 ^{o}C (59.7 ^{o}F; 12.2 - 31.7 ^{o}C [54 - 89 ^{o}F]) the first year (November 11, 2011 - May 30, 2012) and 20.1 ^{o}C (68.2 ^{o}F; 11.1 - 30 ^{o}C [52 - 86 ^{o}F]) in 2013 (February 13 - July 9) which was within the range used by both species. Experiments were terminated when water temperatures became too warm in the summer. Quagga mussels ranged in length from 4.4 – 24.6 mm.

Discussion

Four fish species were found with quagga mussels in their digestive tract. Of these, redear sunfish is the only true molluscivore currently present in the lower Colorado River system. Redear sunfish have rounded molariform crushing teeth on both upper and lower pharyngeal arches that enables molluscivory when fish reach 25-75 mm in length (Huckins 1997; Huckins et al. 2000; Ledford and Kelly 2006; Collar and Wainwright 2009). Our laboratory study found that redear sunfish can consume quagga mussels up to 26.8 mm in length, and that size of predated mussel was correlated with predator size. Redear sunfish are also known to consume zebra mussels up to 20mm in length (French and Morgan 1995; Magoulick and Lewis 2002; Towns 2003).

Redear sunfish prefer vegetated littoral areas with submerged stumps and brush with very little or no flowing water (Pflieger 1975; Trautman 1981; Twomey et al.

1984; Moyle 2002). They were introduced to the lower Colorado River in mid-late 1940's (Minckley 1973) and although not widespread, they are abundant in Lake Havasu. Record sized redear sunfish are continually being captured in Lake Havasu by anglers (e.g., wired2fish.com May 5 2011, March 14, 2013; Arizona Game and Fish Department Fishing Report February 20, 2014), probably in association with the invasion of quagga mussels and a possible increase in redswamp crayfish, *Procambarus clarkii*. Redswamp crayfish introduced to the Colorado River in the 1960's (Inman et al. 1998), were found in stomachs of six of 10 fish species examined including redear sunfish, and were found to consume quagga mussels in laboratory experiments (C. Karp, unpublished data).

We believe that the field enclosures screened any other potential predators from consuming quagga mussels on the brick surfaces. However, we observed juvenile and adult largemouth bass, *Micropterus salmoides* and adult redswamp crayfish in the cove where the study was conducted. Thus, although unlikely, these species may have contributed to the decrease in mussel density observed in some fish enclosures.

Predation by crabs, crayfish, turtles, diving ducks, and over 20 fish species on zebra and to a much lesser degree quagga mussels has been documented (French 1993; Boles and Lipcius 1994; French and Morgan 1995; Tucker et al. 1996; Marsden 1997; Molloy et al. 1997; Thorp et al. 1998; Magoulick and Lewis 2002; Andraso 2005; Bartsch et al. 2005; Bowers and Szalay 2007; Watzin et al. 2008). In a single enclosure study, Wong et al. (2013) suggested that redear sunfish can reduce quagga mussel densities through predation and as such, could potentially be used in biocontrol efforts. Their study provided valuable information but lacked replication. In our study, redear sunfish decreased quagga mussel areal density by as much as 25.3 percent in some field enclosures in just a few months. However, we observed some variability in fish response and found that redear sunfish may consume other prey if available (some redear sunfish stomachs contained redswamp crayfish and other invertebrates). Thus, our study suggests that redear sunfish may help to control but are not likely to eradicate quagga mussels where the two species co-occur.

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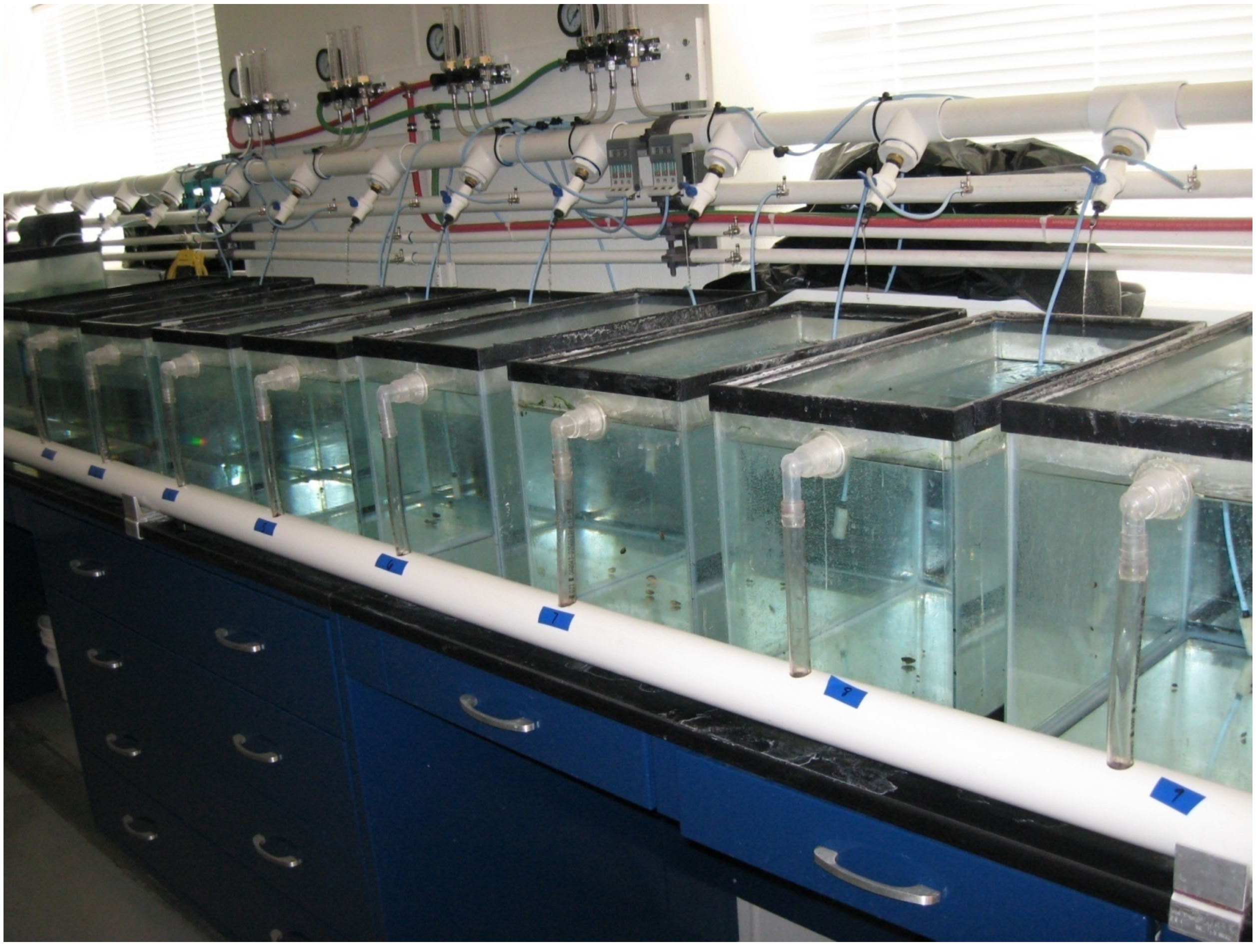
Figure 1. Aquaria used in laboratory experiments (note settled quagga mussels).

Figure 2. Cove just upstream Bureau of Land Management Partner's Point, Lake Havasu, Arizona.

Figure 3. Fish/quagga mussel enclosure pen.

Figure 4. Enclosure pens deployed in cove.

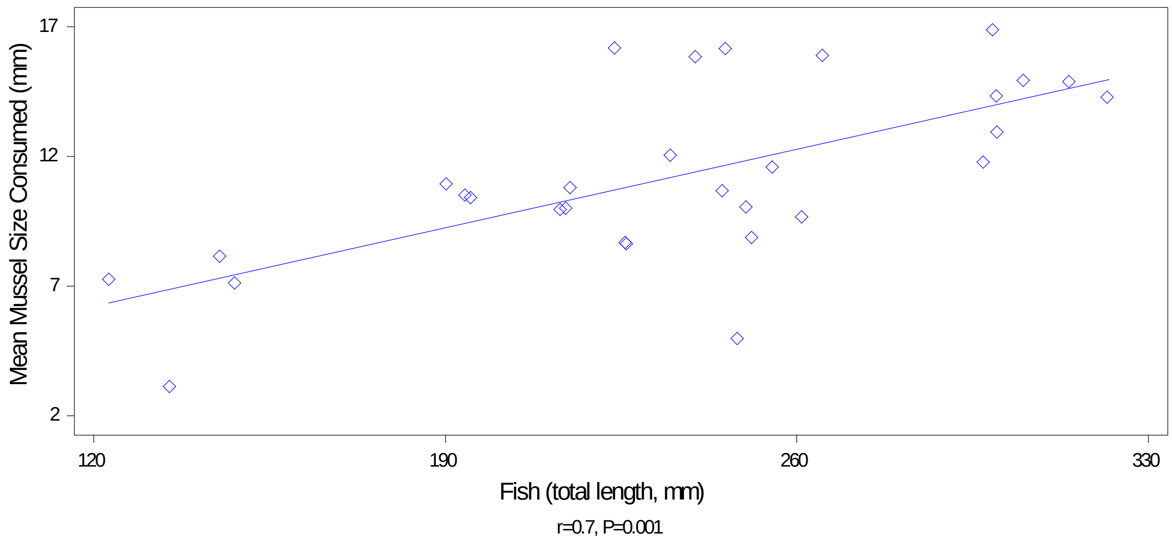

Figure 5. Regression line of Mean Quagga Mussel Size Consumed with Fish Size (Total Length).

Figure 6. Redear sunfish from Lake Havasu.

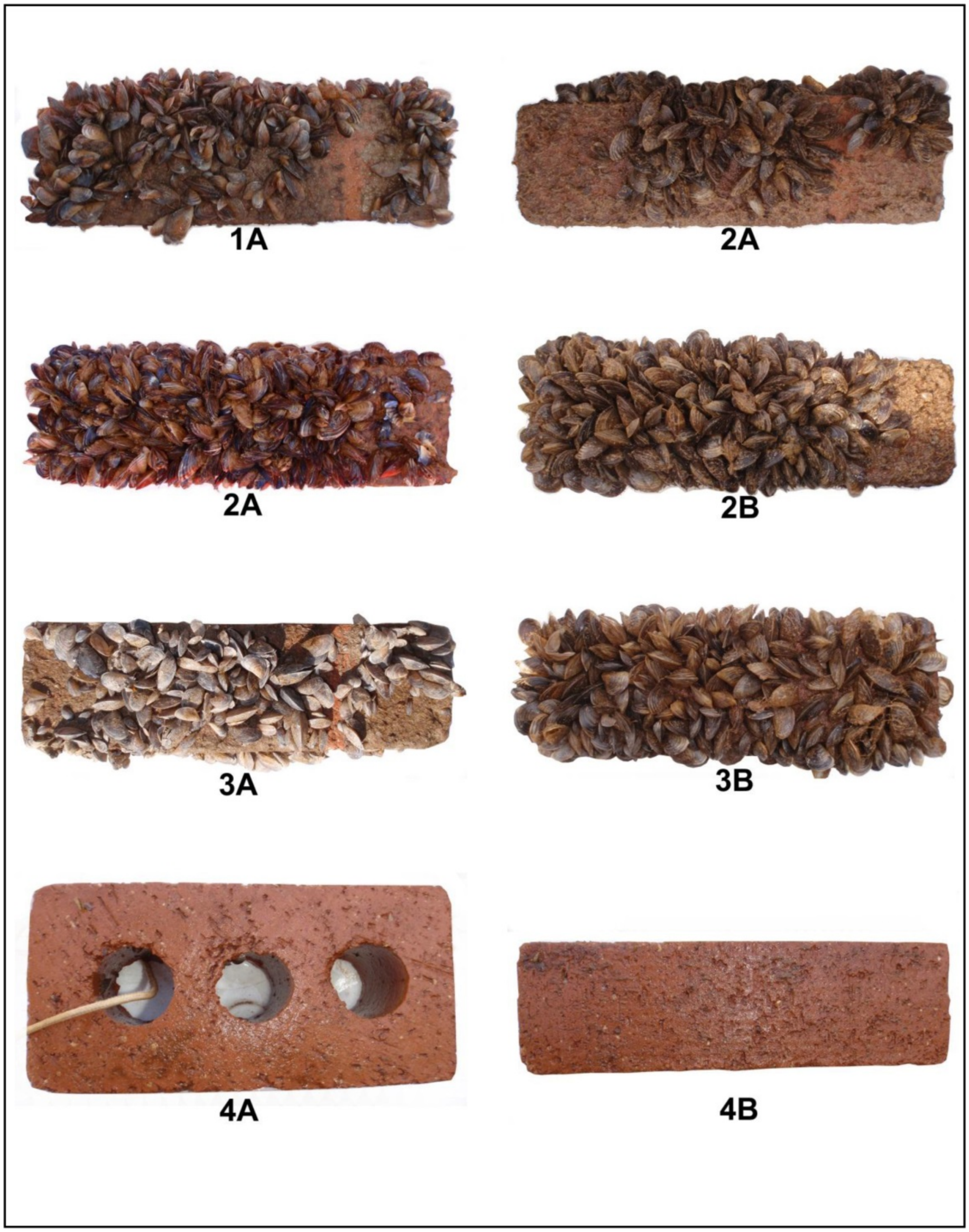

Figure 7. Paired images of brick surfaces with quagga mussel. 1A and 1B is a brick before and after redear significantly consumed mussels, 2A and 2B is a brick in which the fish did not consume a significant amount, 3A and 3B are images from the same control brick surface 5 months apart- note mussel growth over time, and 4A and 4B is a blank after 5 months in an enclosure (< 10 mussels present).

Table 1. Summary of fish stomach contents, from upper Lake Havasu and Lake Mohave, spring 2010.

Species	N	Size (TL, mm)	Contents[1]
Smallmouth bass	9	206-402	fish, crayfish
Largemouth bass	16	290-485	fish, crayfish
Channel catfish	14	340-670	fish, crayfish, snails, quagga mussel (2)[1]
Yellow bullhead	14	258-349	fish, crayfish
Striped bass	11	430-680	fish, crayfish
Black crappie	2	240-316	empty
Redear sunfish	21	185-327	quagga mussel (11)[1], clams, crayfish
Bluegill	3	180-203	quagga mussel (1)[1]
Common carp	15	311-660	quagga mussel (3)[1]
Rainbow trout	4	310-338	empty
RedearXBluegill	1	196	quagga mussel (1)[1]

[1] number in parentheses is # of fish with quagga mussels in stomach

Data Sets that support the final report

Share Drive folder name and path where data are stored:
ENVRES(\\bor\do)(H:)/ENVRES/8668290/KARP/S&Tdata

Point of Contact name, email and phone:
Cathy Karp, ckarp@usbr.gov, 303-445-2226

Short description of the data:
Statistical files: percent mussel coverage, fish and mussel sizes

Keywords: fish predation quagga mussel

Approximate total size of all files: (226KB)