Quagga mussels and their affects on the aquatic system

Introduction

Since the discovery of quagga mussels (*Dreissena rostnformis bugensis*) in the Lower Colorado River reservoirs in early 2007, public agencies have been scrambling to determine how to control their population and distribution. This same species, originally from the Ukraine, infested the Great Lakes region in 1989, competing with their earlier arrived relative, the zebra mussel (*Dreissena polymorpha*). The bulk of North American research has focused on zebra mussels from the Great Lakes, yet as these two mussel species spread to other waters, new research is taking place to better understand the mussels' ecological dynamics in these new environmental settings. These mussels have a high potential for rapidly adapting to new environmental conditions, which could lead to significant long-term impacts in the waters they inhabit (Mills et al., 1996). The quagga mussel is the primary species that has spread westward from the Great Lakes to the Lower Colorado River system (Figure 1). The following is an overview from published research articles of *Dreissena's* habits, tolerances, and its possible influence on water quality, nutrient cycling, and ecological changes in the aquatic system. The genus name, *Dreissena*, is used in this summary where information applies to both species.

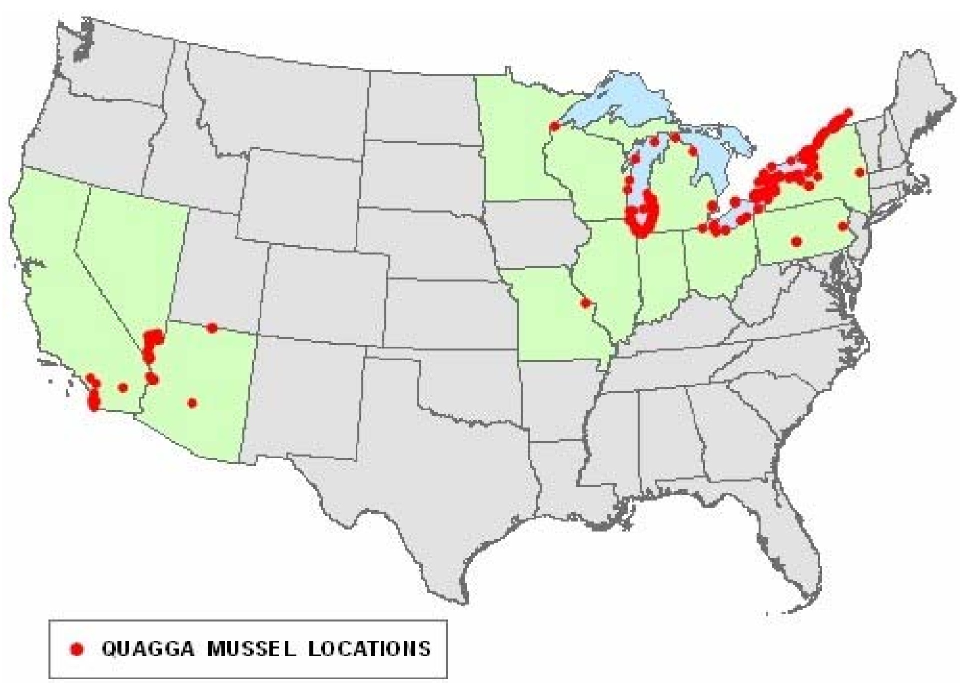

Figure 1: Known quagga mussel distribution as of 2007. (U.S. Geological Survey - http://cars.er.usgs.gov/Nonindigenous_Species/Zebra_mussel_FAQs/Dreissena_FAQs/dreissena_faqs.html#Q8)

Environmental Influences on Distribution

Quagga mussels are able to adapt to varying environmental conditions by being able to colonize hard and soft substrata in varying water depths (Mills et al., 1996). Quagga mussels in Lake Havasu have been found on almost all available surfaces except copper pipe. They have been found in both deep water (up to 425 feet) and shallow water areas of the Great Lakes and are currently thriving in the relatively shallow waters of Lake Havasu, Lake Mohave, and Lead Mead. They do not like light; however, and tend to attach to the underside of rocks in shallow water. In slightly deeper water where sunlight is more diffuse, Dreissena population densities may reach 100,000 individuals per square meter. Over 40,000 quagga mussels per square meter have been reported in Lake Havasu and Lake Mohave one year after its discovery in these reservoirs.

Lab experiments indicate that both zebra and quagga mussels do not tolerate water salinities much over six parts per thousand (ppt) (Setzler-Hamilton et al., 1997), although their tolerance probably increases with multigenerational exposure (Mills et al., 1996). The salinity of the Lower Colorado River increases downstream, but it is not much of a factor as reported total dissolved solid concentrations are less than six ppt.

Quagga mussels are reported to be less tolerant of high water temperatures than zebra mussels, but the fact that they are thriving in the Lower Colorado River reservoirs that obtain water temperatures as high as 86^{o}F during the late summer, indicates otherwise. Additionally, minimum spawning temperatures for quagga mussels is 48^{o}F (Claxton and Mackie, 1998) and as water temperatures in the Lower Colorado River reservoirs are rarely below this level (LaBounty and Burns, 2005), spawning could take place throughout most of the year. Observations of quagga mussels in the Lower Colorado River reservoirs have revealed up to six breeding cycles within the past year. Higher water temperatures have been shown to exert more stress on zebra mussel oxygen consumption rates. Rates in water above 89ºF are over 3.6 times larger than consumption rates at 68°F, yet the mussels had a corresponding 73% drop in filtration rates and an almost 5 fold increase in ammonia excretion rates (Aldridge et al., 1995). Note that this study did not include quagga mussels which may behave differently.

The distribution of quagga mussels is also partially dictated by calcium concentration. Concentrations above 12 mg/l are needed to form the shell material (Jones and Ricciardi, 2005), which is not a problem as concentrations of near 89 mg/l total calcium have been reported in Lake Havasu by the Arizona Department of Environmental Quality (written communication, August 2007).

Feeding Ecology

Dreissena mussels are efficient filter feeders that can siphon more than one liter of water per day by using cilia to pull water, phytoplankton, zooplankton, bacteria, organic debris, silt, and clay through an inhalent siphon (Figure 2; MacIssac, 1996; Snyder et al., 1997). Particulate matter and undesirable algae species are separated in the shell cavity and mixed with mucus to form pseudofeces, which is expelled back out the same inhalent siphon. Excess water is ejected out the exhalent siphon and generated wastes (feces) are expelled through the anus. *Dreissena* species feed so efficiently that they have reduced the total phytoplankton community in Lake Erie by as much as 20% (Barbiero et al., 2006) and they have created conditions that cause species shifts in diatom communities (Idrisi at al., 1998). Lower phytoplankton biomass leads to water clarification, allowing sunlight to penetrate deeper into the water column. Increased sunlight penetration increases the heat potential and evaporation rate of a lake and encourages aquatic plant growth, such as Cladophora, at deeper levels in the aquatic environment, modifying the local ecosystem. Cladophora, a bottom dwelling, filamentous green algae found in Lake Michigan, has been tied to water fouling as it decays and to nourishing and thus increasing E. coli and enterococci bacteria accumulations (University of Wisconsin Sea Grant website, www.seagrant.wisc.edu). Local officials involved with the Lower Colorado River reservoirs have noticed a corresponding increase in both water clarity and the development of green filamentous algae growing on the reservoir bottoms.

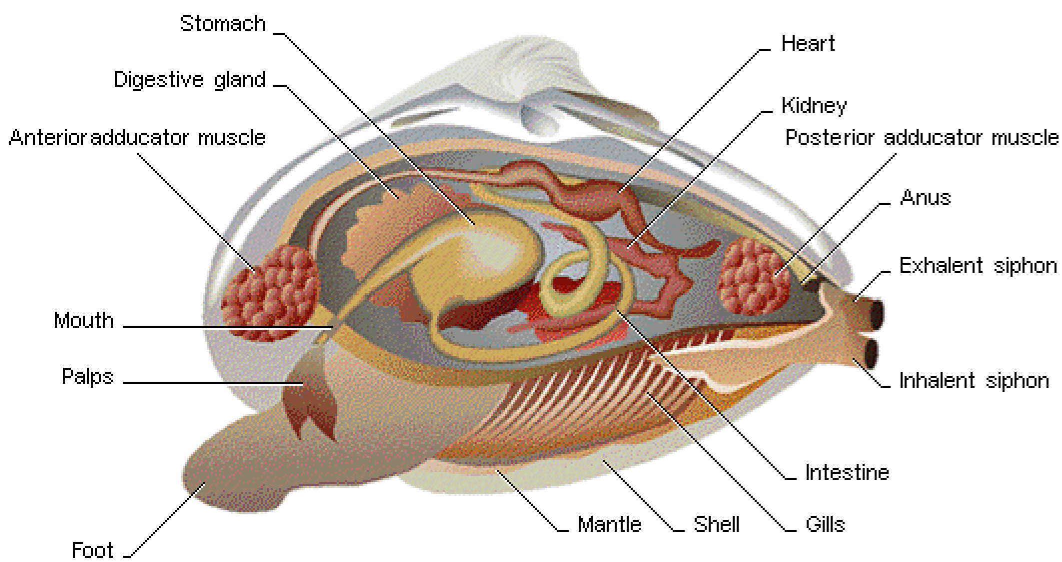

Figure 2: Generalized anatomical diagram of a mollusk (clams and mussels).
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Dreissena have also been shown to selectively reject toxic cyanobacteria through pseudofeces in favor of non-toxic species such as green algae, protozoans, and diatoms, enriching the toxic species along the lake bottom and during cyanobacteria bloom events (Barbiero et al., 2006; Juhel et al., 2006). Microcystins, a cyclic peptide produced by

Microcystis, a colonial cyanobacterium, pose significant ecological problems and health issues to plants and animals, including humans (Vanderploeg et al., 2001). Even if not directly consumed by *Dreissena*, some invertebrate organisms experience a major population decline as they are either out-competed by the mussels for the phytoplankton food source or they become more susceptible to predation because of the lack of other food sources (Wilson, 2003).

Less phytoplankton in the water column also affects the growth potential of larval fish as their food sources diminish, resulting in decreasing sizes in adult fish populations. Suspended inorganic particulates (i.e. sediment) in concentrations above 1 mg/l in the water column; however, reduce water clearance rates and mussel ingestion rates and assimilation efficiencies. This is because the mussels reject most of the inorganic particulates and they are quickly returned into the water column (Vanerploeg et al., 2002). Declining food quality can also cause exponential declines in clearance, ingestion and absorption rates, water processing potential, and assimilation efficiencies (Madon, et al., 1998).

Native or preexisting *Unionid* mollusks are adversely affected by *Dreissena* competition in the Great Lakes, yet other benthic organisms, including amphipod crustaceans and other detritivores, exploit structure associated with or wastes generated by these mussels. Similarly the *Orbicula* clam population in Lake Havasu has severely declined. With the decline of native mollusks, fish populations that feed on the mollusks have also declined as they have had to turn to the less nutritious *Dreissena* species (NOAA Great Lakes Environmental Research Laboratory website, www.glerl@noaa.gov). Organisms that benefit in the presence of mussels are benthic invertebrate species that feed on the mussel's pseudofeces. These organism's abundance and density are higher than in areas devoid of mussels (Bially and MacIssac, 2000). Additionally, *Dreissena* is exploited by a host of predators, most notably waterfowl, fish (including the red-eared sunfish that is present in Lake Havasu), and crayfish. The extreme tendency for mussel proliferation though (up to one million eggs per female per breeding cycle), greatly overshadows the predatory losses and in almost all cases, mussel populations remain unaffected.

Nutrient Relationships and Ecological Effects of *Dreissena*

The growth potential of *Dreissena's* main food type, phytoplankton, is dependant on the abundance of nitrogen nitrates, organic orthophosphates, and dissolved organic carbon in the aquatic environment. Nitrates and dissolved organic carbon are sufficient enough in the Colorado River system for sustainable phytoplankton production, yet the paucity of organic phosphate compounds usually limit over production (e. g. algal blooms) except near sources of phosphates (LaBounty and Burns, 2005). Nitrates and phosphates enter the river system from urban wastes (e.g. septic tanks and effluent disposal), through agricultural practices, and in the case of nitrates alone, from runoff of saturated shallow subsoils in the region during extended high precipitation periods (Wilson et al, 2005). Surface effluent disposal containing elevated phosphorus levels entered Lake Mead between 2001 and 2003 (LaBounty and Burns, 2005). The excess phosphorus input led to algal blooms from 2001 to 2003, with the 2001 bloom extending from Lake Mead to Lake Havasu and even reaching into San Diego's San Vicente Reservoir, which is part of the Metropolitan Water District of Southern California's Colorado River water delivery system. Satellite imagery has also revealed other algal blooms in Lake Havasu (James LaBounty, personal communication, May, 2008). Research connecting *Dreissena* species with nutrient loading and cycling is absent for the Lower Colorado River reservoirs, yet studies from the Great Lakes and other aquatic systems have shown that *Dreissena* mussels can alter the balance of an aquatic system's nutrient uptake and release (remineralization) through their feeding habits.

Zebra mussels can absorb dissolved organic carbon as they filter feed, which could be as much as 50% of their carbon demand (Roditi, et al., 2000). They can also remove a large fraction of chlorophyll from the water column, except when cyanobacteria (i.e. blue-green algae) are present in mass (Gardner et al., 1995). Johengen et al. (1995) determined that the annual mean concentrations for total suspended solids, particulate organic carbon, particulate phosphorus, and particulate silica in the inner portion of Saginaw Bay of Lake Huron were significantly lower and annual means for nitrates and ammonium were higher in 1992 and 1993 (post-zebra mussel) than in 1991 (pre-zebra mussel).

As *Dreissena* mussels filter organic material from the water, they expel ammonium in their pseudofeces and feces, among the highest nitrogen excretion rates of any animal (Bruesewitz et al., 2006). This source leads to enhanced benthic nitrogen regeneration rates, in which protozoans feed on the mussel's waste products. Conversely, zebra mussels have been shown to be a significant sink for phosphorus in phosphate limiting environments (Johengen et al., 1995) and they only affect the total phosphorus in the water column when the annual phosphorus accumulated into mussel biomass represents greater than 20% of the lake's annual phosphorus loading (Mellina et al., 1995). Phosphorus availability is modified; however, by its release into the water column from protozoans grazing on mussel pseudofeces. This process may explain the development of Microcystis blooms in relatively phosphorus limited Saginaw Bay in Lake Huron (Vanderploeg et al., 2001).

Dreissena mussels in Lake Superior have been found to remove chlorophyll at a higher rate than they remove total phosphorus (Nicholls and Standke, 1996). This removal-rate difference has led to a 60 percent decrease in the summer chlorophyll-to-total phosphorus ratio; i.e. there is less planktonic algae in the water column for other organisms to eat. Research on mussel populations in lakes Erie and St. Clair indicate that the nutrient-chlorophyll relationship is modified when mussel population densities are high or if mussels inhabit very shallow lakes. Although a change in the natural nutrient-chlorophyll ratio has also been observed in other the Great Lakes, no evidence was found for increased decoupling of this relationship with increasing zebra mussel density in European lakes.

Modification of the balance of aquatic nitrogen and phosphorus cycles paradoxically can facilitate phytoplankton and cyanobacteria growth in well mixed shallow areas due to microbial grazing on pseudofeces that release the nutrients back into the water column and into the surface sediments (Gardner et al., 1995; Conroy, et al., 2005). A study in the Upper Mississippi River showed that sediment denitrification rates, the process of changing reduced nitrogen compounds (e. g. ammonium) to more oxidized compounds (nitrate), are higher in zebra mussel infested areas compared to areas devoid of the mussels (Bruesewitz et al., 2006). Pseudofeces rich in ammonium initially enhance nitrogen mineralization and increases pore water ammonium concentrations in the surface sediment, yet associated organism activity in the sediment releases nitrates back into the water column. Denitrification in the sediment and phosphorus regeneration from mussel pseudofeces on the lake bottom may explain excessive Cladophora growth in Lake Michigan (University of Wisconsin Sea Grant website, www.seagrant.wisc.edu) and could lead to more phytoplankton production.

Documented plankton species shifts associated with zebra mussel invasion reveal that the new dominant species require higher phosphorus optima and tolerances for efficient productivity, which can further stress the aquatic environment (Idrisi et al., 2001). Species shifts directly influenced by zebra mussel feeding activity, particularly in diatom communities, have also led to increases in silica concentration in the water column and decreases in alkalinity. Although too soon to measure in the Lower Colorado River system, quagga mussels in this ecosystem may affect similar trends. As *Dreissena* mussels modify existing nutrient and chemical cycles by increasing the availability of these nutrients, experts indicate that lower nutrient input into the aquatic system is necessary to offset the mussel affect (Culver, D. A., Ohio State University, Testimony on July 28, 2002; Congressman James Oberstar, May 12, 2008). Dr. Henry Vanderploeg, research ecologist for the National Oceanographic and Atmospheric Agency at the Great Lakes Environmental Research Laboratory echoes that added nutrients into an aquatic system with *Dreissena* mussels would probably lead to greater problems, such as the massive development of nuisance algae such as Cladophora (written communication, June, 2008). He added that any developing problems are site specific and could vary in type and magnitude.

Bioconcentration of Dissolved Compounds

Mollusks as benthic filter feeders are well known to concentrate various contaminants such as heavy metals and modified organic compounds from the water column. These pollutants are concentrated within the mollusk's tissue, at high enough levels to use the mollusk as an environmental indicator. *Dreissena* is not an exception. Numerous studies in North American and Europe of heavy metal and chlorinated organic compound accumulations in zebra mussels have shown they are an excellent indicator for aquatic environmental conditions (Kwan et al., 2003; Bervoets et al., 2005). Although the mussels have shown signs of endocrine disruption due to pollutant exposure (Binelli et al., 2004), the bigger potential threat is to higher trophic organisms that may feed on the mussels. As *Dreissena* are eaten by predators, contaminants are able to further bioconcentrate up the food chain.

Dreissena mussels may accumulate organic pollutants within their tissues to concentrations more than 300,000 times greater than those in the surrounding environment (Snyder et al., 1997). These and other pollutants are also present in their pseudofeces, which can be passed up the food chain via foraging organisms, therefore increasing wildlife exposure to these pollutants. Variably weathered fossil fuels such as polycyclic aromatic compounds (PAC) and alkylated derivatives have been detected in *Dreissena* mussels (Hellou et al., 2006). Other organic compounds found concentrated in zebra mussels in a disposal pond adjacent to Lake Erie in Buffalo, New York include fluoranthene, pyrene, chrysene, benzo(a)anthracene , and PCB Aroclor 1248 (Roper et al., 1996). *Dreissena* mussels also can absorb and accumulate heavy metals such as arsenic, chromium, cadmium, silver, nickel, lead, zinc, copper, and mercury, with several of these metals needing to be in the presence of high molecular weight dissolved organic carbon to absorb into the mussel's tissue (Roditi, et al., 2000; Berny et al., 2003).

Accumulation of these contaminants in the mussel represents a potential threat to fish and birds that prey on them. *Dreissena* mussels and other bottom dwelling exotic species in Lake Erie have modified the aquatic food web from pelagic-based to benthic(lake bottom)-based, which introduces a potential new route for contaminant transport to higher trophic levels (MacIssac, 1996; Southward-Hogan et al., 2007). Lead concentrations in tissue mass decreased through to the top predators (e. g. smallmouth bass), but mercury concentrations increased through the same path. Berny et al. (2003) tracked cadmium bioaccumulation from zebra mussels to higher trophic levels (ducks in this case) in Lake Geneva, Switzerland and found that this phenomenon is probably long term (years vs. months), but some chlorinated hydrocarbons such as lindane, an insecticide, tend to bioaccumulate quickly. Waterfowl predators that consume contaminated *Dreissena* have been reported containing elevated concentrations of organic pesticides and polychlorinated biphenyl compounds (MacIssac, 1996).

Remarks

Although the above research has focused in environments different than what exists in the Lower Colorado River region and different incident species are involved, the potential for similar trends to transpire is real. Water clarification as a result of quagga mussel feeding has been noted in Lake Mead and Lake Havasu. The above presented research indicates a relationship between *Dreissena* mussel feeding habits, nutrient loading and cycling, ecological shifts, and the bioaccumulation of contaminants, all of which result in changes of water quality and a potential threat to the health of the ecosystem, including humans. Nutrient loading from outside sources (i.e. septic tanks, effluent runoff, urban runoff, and agricultural practices) offer an extra food source for phytoplankton and aquatic plant growth. The mussel's ability to alter the ecological community, shift chemical balances and thus water quality, and potentially threaten recreational activities (in the form of sport fishing – if the fishes food sources deteriorate and/or if contaminants make their way up the food chain) highlights the need to determine how to control these mussels. Taking the advice of Dr. Culver, Dr. Vanderploeg, and Congressman Oberstar, nutrient loading modifications are needed to slow the potential alteration due to the presence of the quagga mussel.

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