

Quagga Mussels (*Dreissena bugensis*) and Zebra Mussels (*Dreissena polymorpha*)



Zebra and quagga mussels, *Dreissena polymorpha* and *Dreissena bugensis* respectively, are two infamous aquatic invaders. These bivalve, filter feeders negatively affect water related economies and can wreak havoc on aquatic ecosystems. Zebra mussels are currently established on the edges of the Adirondack Park in Lake Champlain and Lake George (USGS, 2012). Quagga mussels have yet to reach the inner boundaries of the Park but thrive in waters closely surrounding (USGS, 2012). Both of these species' life cycle, high fecundity, and microscopic veliger stage allow for easy dispersal and establishment within and between water bodies. However their ecological requirements, like calcium concentration, could help keep zebra and quagga mussels from successfully establishing and becoming a nuisance in the some Adirondack waterways (Hinks & Mackie, 1997).

Zebra and quagga mussels are very similar species that were once considered the same (Rosenberg & Ludyanskiy, 1994). However genetic analysis has determined them to be two distinct species. Anatomically they share shell coloration (black, white, or both), striation, and size (2.3-2.5cm) but have differing shell shape. A quagga mussel's ventral side is convex with the ventral lateral margin lacking an acute angle; while a zebra mussel's ventral side is typically flattened with an acute lateral-ventral angle. Simply if a quagga mussel is placed on their ventral side they would topple over whereas a zebra mussel would remain upright on its ventral side.

Additionally the life cycle of the *D. polymorpha* and *D. bugensis* are analogous, varying with size and time in the specific developmental phases. Both species have two major life stages: planktonic

larval and sessile, dioecious adult (Ackerman, Sim, Nichols, & Claudi, 1994; Claudi & Mackie, 1994; Nichols, 1993). During the winter mussels that are greater than 8mm in length go through oogenesis and spermogenesis (development and maturation of egg and sperms, respectively). In the spring when water temperatures reach around 12°C the spawning period begins. It peaks when temperatures increase to 15-17°C and last 3-5 months. Throughout spawning mussels release their gametes directly into the water column where external fertilization takes place. A single female is estimated to excrete 300,000 to 1,600,000 eggs per breeding season (Neumann, Borcherding, & Brigitte, 1993).

Once fertilization takes place the larvae's life cycle take about four weeks to complete. There are several distinct larva stages: veliger, post-veliger, and settlement (Claudi & Mackie, 1994). The veliger stage occurs shortly after fertilization. Veligers are planktonic, microscopic, and easily dispersed during this period by water currents or anthropogenic activities (i.e. ballast water intake) (Claudi & Mackie, 1994). Several days after fertilization the larvae then secrete a D-shaped shell and later secrete a second clam-like shaped shell. Organ system development and the settlement of the free swimming clam-shaped larvae (200-250um) preclude the post-veliger and settlement stages (Nichols, 1996). In these phases maturation is continued with the growth of a foot (pediveliger larva) for free-swimming or crawling along to bottom of the water body to encounter an appropriate surface for attachment. Upon a proper substrate the pediveliger will secret a byssal thread and undergo metamorphosis to a plantigrade larva. However, without an appropriate surface to settle on, metamorphosis is delayed which includes growth of gills, loss of velum, and secretion of the adult shell. On a suitable substrate the plantigrade can complete larva development by growing a foot and mouth which gives the mussel its distinct triangular shape. Once metamorphosis is completed the plantigrade enters adult development as a juvenile.

Dreissena sexually mature relatively quickly. Larvae that are born in the spring and settle by mid-summer can reach sexually mature sizes (8-10mm in shell length) by the end of the spawning season and contribute to a fall recruitment of offspring (Claudi & Mackie, 1994). However it is important to note that water temperature has an inverse relationship with growth and development rates of larvae and adults. Therefore colder water temperatures will slow the maturation and reproductive rates of zebra and quagga mussels (Garton & Haag, 1993).

They can survive a myriad of conditions, but like all living organisms zebra and quagga mussels have their limits and thresholds. The mussels can tolerate starvation for extended periods, desiccation (10 days at 15°C with high humidity, less than 150hrs at 25°C regardless of humidity), extremes of high and low temperatures, and varying dissolved oxygen levels (Claudi & Mackie, 1994). However calcium concentration seems to be the most influential factor for establishment, growth, and reproduction (Hinks & Mackie, 1997). General calcium requirements are 3mg Ca/L for survival, 7mg/L for growth, 12mg Ca/L for reproduction, and 25mg Ca/L for massive growths (Claudi & Mackie, 1994). In the field zebra mussels have displayed 100% mortality within thirty-five days at calcium levels below 8.5 mg Ca/L with a pH of 8.4 or less. In waters with 20-48 mg Ca/L and pH of 8.2-9.3, zebra mussel adult survival was 52-100% in the cohort (Hinks & Mackie, 1997). Through a logistic regression for calcium zebra mussels have shown negative growth below 8.5 mg Ca/L and maximum growth at 32 mg Ca/L (Hinks & Mackie, 1997). Another study has found zebra mussel populations existing at 8 mg Ca/L in the St. Lawrence River, while quagga mussels have been absent below 12 mg Ca/L (Jones & Ricciardi, 2005). These finding may suggest that quagga mussels may have higher calcium requirement than zebra mussels.

D. polymorpha and *D. bugensis* for the most part occupy two different niches, which allow them to initially coexist at depths from 8-110 meters (Berkman, Garton, Haltuch, Kennedy, & Febo, 2000; Mills et

al., 1999). Zebra mussels are most notably associated with a firm attachment to hard substrates because their D-shape and byssal threads (Mills et al., 1999; Mills et al., 1993). However ten years after the initial colonization of zebra mussels, Berkman et al. (2000) has found populations on softer strata (sand, silt, mud) adjacent to the original hard strata colony. On the other hand quagga mussels are more associated with soft substrates and deeper, cooler waters (found at depths of 130m), but more frequently quagga mussels have been displacing zebra mussels from the rocky littoral zone within 4-12 years after their establishment (Berkman et al., 2000; Mills et al., 1999; Mitchell, Bailey, & Knapton, 1996; Spidle et al., 1995).

Both of these mussels' dispersal capacities and high fecundity have enabled their rapid establishment in their nonindigenous regions. Native to parts of Europe, they have been transported to the Great Lakes basin by ballast water discharge from transoceanic vessels (Hebert, Muncaster, & Mackie, 1989). The zebra mussel is native to waterways of southern Russia, and has been established in North America at St. Clair Lake since 1989 (Hebert et al., 1989). As of 1991 the quagga mussel, native to the Dnieper River drainage of Ukraine, has been found in the Erie Canal and Lake Ontario (May & Marsden, 1992). Within a few years after initial colonization, the two have spread quickly throughout the Great Lakes, Finger Lakes, St. Lawrence River, the Mohawk and Hudson River drainages (Mills et al., 1996). Since the mid-1990s zebra mussels have been established on the borders of the Adirondack Park in Lake George and Lake Champlain (USGS, 2012).

Their primary dispersal capabilities occur in the pelagic state of the mussels with veligers and post-veligers. These microscopic, planktonic larvae can easily disperse by water currents. Additional spread from one water body to another is mediated by humans if veligers enter bilges, live wells, ballast tanks, and engine water (Claudi & Mackie, 1994). Furthermore larvae can attach to floating logs, aquatic vegetation, and other debris that could be transported within the water way or to another water body (Claudi & Mackie, 1994). Secondary spread usually occurs within an invaded water body by drifting post larvae and young adults using byssal and/or mucous threads and is generally a small distance (Claudi & Mackie, 1994).

Dreissenids' filter-feeding life style and large populations of up 750,000 individuals per square meter can have many impacts on an aquatic ecosystem. They directly displace indigenous bivalve communities by outcompeting them for habitat and nutrients (Mills et al., 1999). Not only do they destroy native mussel (Unionoida) populations, but they also effect water quality and lower trophic levels (Ricciardi, Neves, & Rasmussen, 1998). Through a meta-analysis large reductions in open water zooplankton and phytoplankton have been identified where dreissenids are established, which can account for increased water clarity. Furthermore quagga and zebra mussel colonized benthic habitats have shown a dramatic increase in algal and macrophyte biomass, sediment-associated bacteria, and total zoobenthic biomass (includes dreissendids) (Stewart, Miner, & Lowe, 1998). Both of these finding suggest a shift in energy pathways from open water environments to a more productive benthic-littoral zone with nutrients being trapped in the sediments rather than suspended in the water column. This energy shift associated with *Dreissena*'s establishment can increased water clarity (Higgins & Vander Zanden, 2010).

The increased water clarity can be misleading because zebra and quagga mussels are essentially concentrating the nutrients in the sediment or benthic regions. The sediment confined nutrients can easily re-suspend in turbid/shallow areas and lead to phytoplankton/cyanobacteria blooms, an increased trophic state, and decreased water quality (Conroy et al., 2005). Additionally, zebra and quagga mussels' intermediate filtration rates result in dense populations excreting large amounts of dissolved nutrients, especially nitrogen in the form of ammonia (Conroy et al., 2005). This excess

defecation may supply limiting nutrients to benthic primary producers and can lead to dissolved oxygen depletion (Conroy et al., 2005; Pimental et al., 2005). The lower trophic levels directly and indirectly affected by these invasives can ultimately alter higher trophic levels in the aquatic ecosystem.

Not only do these invaders change water chemistry and aquatic habitats, but they also cost industry billions of dollars a year in lost production and management (Higgins & Vander Zanden, 2010; Pimental et al., 2005; Stewart et al., 1998). Since they can form thick densities, the greatest economic damage is caused by the fouling and clogging of pipes, pumps, boat hauls, or other components of municipal or industrial water systems. Particularly, impacted facilities and economies have included municipal drinking water systems; hydroelectric power plants; water flow/level control facilities; irrigation systems; navigation equipment (buoys, locks); and lowered real estate values (Department of Santa Barbara County Parks [DSBCP], 2008; Pimental et al., 2005). Additionally the tourism industry may be impaired by the masses of shells on beaches and swimming areas that can cut recreationalists (Claudi & Mackie, 1994).

The impacts on the environment and industry caused by zebra and quagga mussels have resulted in mitigation efforts. Once established there are control options that can be implemented to manage and potentially eradicate quagga and zebra mussel populations. In Lake Mead, Nevada/Arizona the DSBCP (2008) reviews different methods for eradication/control (Claudi & Mackie, 1994):

- Water level manipulation
- Isolate with barriers or coverings and then treat with effective biocide such as potassium chloride, copper sulphate, and sodium hypochlorite.
- Benthic mats
- Use of heat, chemical, and mechanical removal on biofouled intake pipes or other equipment
- Antifouling coating in the form of TBTO (tributyl tin oxide, an organotin oxide), copper, or nontoxic silicone based coating

All of these methods come with a huge cost, and preventing quagga and zebra mussel from establishing pestiferous growths is the only way to eliminate the negative impacts on the environment and industry (Claudi & Mackie, 1994).

These European invaders are extremely taxing in waters throughout the United States. Since they are well adapted for a variety of habitats, tolerable to extreme abiotic condition, highly fecundate, and have effective dispersal methods, they have been able to naturalize throughout the Northeastern US. These invaders are troublesome to the environment and economy, and millions of dollars a year are spent to fix problems caused by biofouling. Zebra mussels have successfully established themselves at Lake George and Lake Champlain inside the Adirondacks while quagga mussels slowly encroach. Some Adirondack water bodies have similar water chemistry to which zebra and quagga mussel inhabit; so it is essential to keep zebra and quagga mussels high on the invasive aquatic radar.

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