<u>Asian Clam *(Corbicula fluminea)*</u>

Asian Clam (*Corbicula fluminea*) is among the three worst non-indigenous invaders in the United States (Pimental, Zuniga, & Morrison, 2005). This bivalve mollusk indigenous to Asia, Australia, and Africa now currently inhabits freshwater habitats in the Americas and Europe. Costs associated with its damages and management are around $1 billion per year (Araujo, Moreno, & Ramos, 1993; Pimental et al., 2005). Asian clams' rapid growth, early sexual maturity, short lifespan, high fecundity, and extensive dispersal capacities make this one of the most successful and threatening invasive aquatic species (Sousa, Antunes, & Guilhermino, 2008). Asian clam has successfully established populations in the Adirondack Park at Lake George since 2010 (Lake George Association, 2012). With such a close proxy and its biological characteristics, Asian clam could easily inhabit the interior waters of the Adirondacks.

Asian clam has been found outside of its original distribution (Asia, Africa, and Australia) since the 1920s on the Pacific Coast in the United States. Initial Asian clam establishment in North America is thought to be due to transoceanic ballast water exchange and Chinese immigration for a food resources (Johnson & McMahon, 1998). With rapid, long distance colonization through ballast/bilge/engine water transport; food resource trade; bait release; aquarium industry; and anthropogenic mediated hitchhiking, Asian clam has quickly spread throughout the United States. Currently it inhabits water bodies in nearly all 50 States and throughout New York (Sousa et al., 2008; USGS, 2012). The Adirondack Park is surrounded by successful Asian clam populations in the Erie Canal at Utica, Champlain Canal at Fort Edward, the Finger Lakes, and St. Lawrence River in Quebec (USGS, 2012). As of 2010 Lake George, on the exterior of the Adirondack Park, has supported Asian clams with growing distributions throughout the lake (Bauer et al., 2012; USGS, 2012).

Asian clams' life cycles and physiological adaptations make them very effective invaders. These bivalve mollusks are hermaphroditic which can self-fertilize (McMahon, 2000). Fertilization occurs in the paleal cavity, and larvae are incubated in the branchial water tubes where they are protected in a nutrient rich environment. When the larvae mature, the juveniles are released into the water and bury into the substratum sediment (Sousa et al., 2008). Juveniles are relatively small, around 250um, completely formed, and easily dispersed via water currents and anthropogenic activities. They anchor to sediments, vegetation, and other hard surfaces (i.e. boat hauls) with mucilaginous byssal thread. When there are turbulent flows or other disturbances, they can re-suspend and be subjected to further dispersal (McMahon, 2000). Asian clams have high assimilation and filtrations rates which enable sexually maturity 3-8 months after fertilization (Sousa et al., 2008).

The adult Asian clam lives 1-5 years and spawns 1-3 times per breeding season (depending on biotic and abiotic factors) (McMahon, 2000; Phelps, 1994; Sousa et al., 2008). Hermaphroditic adults have high fecundity, and an average individual can produce around 35,000 larvae per breeding season (McMahon, 2002; Mouthon, 2001). However, Asian clams have a low juvenile survival and a high mortality rate throughout its lifespan which lead to populations dominated by high proportions of juveniles (McMahon, 2002; Sousa et al., 2008). Asian clam's life history adaptions and reproductive traits allow massive population densities to form when invading a new habitat or after subjection to environmental stress (McMahon, 2002).

These characteristics also enable Asian clam to achieve high densities in varying aquatic habitats and ones susceptible to environmental perturbations. They thrive in well oxygenated rivers and oligotrophic lakes with sandy or gravel substrates but are also found in turbid waters, under large boulders, or in soft silts of deep lakes (Sousa et al., 2008). Typically they are found buried within the top 10-15cm of the substrate in 2m to greater than 40m of water with highest densities occurring between 3-10m depths (Wittman et al., 2008). It can tolerate pH as low as 5.4, and if pH is greater than 6.5 it can inhabit waters with calcium levels of 6mg Ca/L (McMahon, 2002; Sousa et al., 2008). Additionally Asian clams can survive wide temperature ranges between 2-36^{o}C (McMahon, 2000; Johnson & McMahon, 1998). Another characteristic that makes Asian clam an efficient invader is their emersion tolerance; they can survive for 36 days out of water at 20^{o}C in relatively high humidity (McMahon, 2002).

Asian clams' economic and ecological impacts are large. They cost industry around a billion dollars a year from clogging intake/water filtration pipes, damaging electric generating plants through biofouling, in management, and tourism industry losses (Pimental et al., 2005). For example the Lake George Asian Clam Rapid Response Task Force (LGACRRTF) has spent over a million dollars on management since 2010 with over $600,000 in 2011. While the infrastructures lost from Asian clam's destructive qualities are expensive but recoverable, the damage to the environment caused by this invader and its management may be irreversible.

Asian clam's negative effects are most noted on the native mollusk populations. Firstly Asian clam's burrowing and bioturbation activity in to the sediments may displace or reduce habitats of the native bivalves (Araujo et al., 1993). They also directly compete and limit planktonic food availability to native mussels (Araujo et al., 1993). Furthermore, when Asian clams form dense populations, they may ingest large amounts of unioid sperm, glochidia, and newly metamorphosed bivalve juveniles (Sousa et al., 2008).

This invasive not only directly impacts native species but also can indirectly affect flora and fauna by altering the water chemistry. Due to its high filtration rates, Asian clams excrete elevated levels of nitrogen and phosphorus in the lake-sediment interface, leading to green algae blooms and dissolved oxygen depletion (Phelps, 1994; Wittman et al., 2008). Similarly, algae blooms and dissolved oxygen exhaustion can transpire from an Asian clam mass die-off (Johnson & McMahon, 1998). Water quality is further impacted by the increased levels and bioconcentration of calcium due to intense shell deposition (up to 4.7cm deep has been observed) (Phelps, 1994; Wittman et al., 2008). This calcium accretion may lead to the invasion of other nonindigenous species with higher calcium requirements like zebra or quagga mussel (Wittman et al., 2008). Additionally, changes in water chemistry by Asian clams have been associated with the decrease in aquatic submerged macrophyte populations. This can be followed by modifications throughout the entire aquatic ecosystem, from zooplankton to migratory birds (Phelps, 1994).

Since Asian clam colonization has negative ecological effects and cost industry huge amounts of money, it is important to develop a comprehensive management plan. The Asian Clam Work Group in Lake Tahoe, NV, CA has developed a four phase management system for dealing with established Asian clam populations which follows (Wittman et al., 2008):

1) The initial management response, urgent actions, and immediate science need for surveying and understanding of the species' biology to fully evaluate the invasion so attainable management goals can be set/established and resources can be allocated properly
2) Selection of preferred management practices based on the above results to achieve management goals at the lowest environmental and economic cost
3) The implementation of selected control actions
4) Long-term monitoring to evaluate success and adapt future management

The three main methods used for controlling or eradicating (depending of invasion and reactiveness) established Asian clams include (Johnson & McMahon, 1998; Wittman et al., 2008):

- Benthic Barriers
- Suction Dredging
- Chemical→Molluscicides in the form of potassium

It is suggested that the integration of these methods could have the most effective results. However all management practices for controlling established Asian clam populations are fiscally expensive, require tons of man hours, and come with environmental degradation (Wittman et al., 2008).

A diver places benthic barriers to eradicate Asian clams. Photo by Emily DeBolt.

The LGACRRTF has extensively managed Asian clams in Lake George since they were first discovered in 2010 (Bauer et al., 2012). Their practices include the application of benthic barriers and suction dredging. Some surveyed benthic mats have displayed a 99% mortality on Asian clams underneath (Bauer, et al., 2012). However not all mats result in 99% mortality, make it through to treatment season, and cover all Asian clams that occupy the lake (Bauer et al., 2012). Suction dredging has been also employed, but results have not met the LGASRRTF expectations because of the high numbers of sampled living clams after treatment (Bauer et al., 2012). It is important to keep in mind that Asian clams are self-fertilizing (hermaphroditic) and one clam can give rise to around 35,000 offspring the next season (Sousa et al., 2008). Furthermore, their life history and reproductive traits encourage them to re-establish quickly after environmental catastrophe like suction dredging or benthic barriers.

Asian clams are one of the worst aquatic invaders in the United States. It has cost the economy millions of dollars each year in fouling, management, and tourism (Pimental et al., 2005). The effects of Asian clam range from out-competing native mollusk to bioconcentrating calcium which could enable other invaders' establishment, particulary zebra and quagga mussels. Like other invasive species, the ecology of Asian clam make them etremely successful colonizers and difficult to manage because high frecundity and multipledispersal mechanisms (Sousa et al., 2008). With Asian clam's preexisting establishment in water bodies surrounding and within Adirondack Park, biological knowledge and spread prevention are imperative to reduce the its further colonization into the heart of the Adirondacks (LGA, 2012; USGS, 2012)

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