Henry Hurt
16th of November, 2019
ENVR 391, Lookingbill


# Senior Capstone Final Paper: Exploring Options for Mussel Restoration

- **Abstract**

This paper seeks to explore the feasibility and possible procedures of restoring freshwater mussels to the Little Westham Creek (LWC) as a way to reduce excess organic pollutants such as nitrogen and phosphorus coming from upstream. To this end, the use of mussels in bioremediation and restoration procedures found in scientific literature were reviewed with the goal of creating a guideline of how such a project would be carried out at the Gambles Mill Eco-Corridor. Based on the results of past literature, water data collected by students in this seminar, and data from RES, it was estimated that a full restoration of mussels with a robust population has the potential to remove up to 5 tons of total suspended solids (TSS) and 200 pounds of Nitrogen per year. As a first step to achieving this, I suggest a project using mussel test cages containing *Elliptio complanata* (Eastern Eliptio) mussels be deployed to assess the suitability of the LWC for a larger restoration effort. Such a project could be carried out as a part of various biology classes as an educational component and is estimated to cost approximately $810 up front at most. If results indicate that the LWC is a suitable habitat, a further restoration could be attempted using the *Elliptio complanata* at a later time.

- **Background - mussels**

Freshwater mussels are a vital part of aquatic ecosystems that are in severe decline, and their restoration has high potential to be incorporated into stream restorations as a natural mechanism to improve water quality. Freshwater mussels are one of the most endangered phyla in Virginia, with 72% of all species in the United States and just over half of all species in Virginia listed as endangered. There are 23 species in Atlantic slope rivers of Virginia alone, including the James River (Jones 2015). The primary causes of their decline have been pollution, overharvesting, dam construction removal of fish host species, and introduction of invasive mussels (Cheng & Kreeger 2017, Jones 2015, Nobles & Zhang 2015).

Mussels and other bivalves are filter feeders that have a great impact on water bodies by filtering out nutrients from sources such as fertilizer runoff that leads to eutrophication, thus improving water quality (Zajak et. al 2018). Mussels consume food by filtering water and consuming organic molecules and plankton. This facilitates denitrification in aquatic ecosystems by converting nitrogen and phosphorus to biodeposits that are more accessible plants and microbes that perform denitrification, which in turn helps prevent eutrophication by removing excess nutrients from aquatic ecosystems (Figure 1) (Hoellein et al. 2017, Ray, Kangas, & Terlizzi 2015). Conservative estimates hold that mussels can remove at least 25% of filtered matter from the streamflow (Cheng & Kreeger 2017). This feature of mussels has been widely used in the Chesapeake bay with oysters. Restoration of historic oyster beds for commercial harvesting and ecosystem services there has been generally successful (Hoellein et al. 2017, Ray, Kangas, & Terlizzi 2015). Although it could be inferred that benefits of mussel restorations in freshwater streams in terms of ecosystem services and biodiversity would be comparable, they have not been studied to the same extent (Hoellein et. al 2017).

- **Water conditions in Gambles Mill Eco-Corridor**

Water sampling conducted before and after the restoration at Gambles Mill Eco-Corridor indicates that there are ongoing problems with nitrogen and phosphorus overload. Research conducted by Emily George during this course indicates that prior to restoration, the average nitrogen concentration in the LWC was 1.162 mg/L and the average phosphorous was 0.077 mg/L. Post-restoration, nitrate concentrations increased to an average of 1.52 mg/L and 2.65

mg/L for phosphates (Figure 2) (George 2019). In addition, it was determined that the TSS in LWC is being decreased due to the improved flow structure of the stream, along with nitrogen and phosphorus concentrations. Despite this improvement, these values are still at the maximum values for a healthy stream, which are 1.0 mg/L of total Nitrogen and 0.025 mg/L of Phosphorus (Riedl 2019). Therefore, using the ecological services of mussels as water filters would provide a tangible benefit to the Gambles Mill Eco-Corridor Restoration.

**Figure 1:** Diagram of how mussels facilitate the cycling and removal of nitrogen from streams.

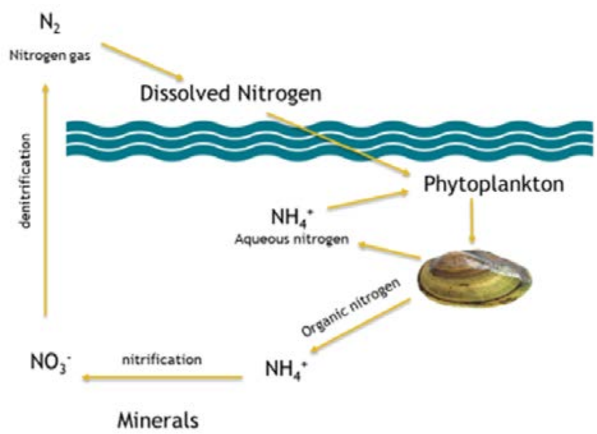


**Table 1:** Concentrations of Nitrates and Phosphates in the Little Westham Creek spring 2018 through summer 2019 (George 2019, Reidl 2019)

| | Post-Restoration | | | Pre-Restoration | |
|---|---|---|---|---|---|
| Mg/L | max | min | avg | avg | Standards |
| Nitrates (mg/L) | 2.7 | 1.2 | 1.52 | 1.4 | < 1.0 |
| Phosphates (mg/L) | 3.8 | 2.5 | 2.65 | 63.5 µg/L | < 25 µ/L |

- **Goals of restoration**

In this paper, I provide an outline of preliminary steps that the University of Richmond could take to determine if restoring mussels to the Gambles Mill Eco-Corridor is feasible and if it would have a significant effect on water quality. The primary question that I sought to answer was what mussel species would be the best to install in the Gambles Mill Eco-Corridor based on five criteria of availability, habitat, filtration rates, fish hosts, and stress tolerance. The hypothesis was that there would be some difference between available native species in terms of how suited they are to the stream conditions. Measurable goals of an eventual full restoration would include establishing a viable population of native mussel species and improving water quality using natural processes in a cost-effective manner. Short term goals for a testing project would include finding if the Gambles Mill Eco-Corridor is an appropriate site for a larger mussel restoration in terms of water quality, measuring what water quality conditions are correlated most closely with mussel health, and providing an experimental learning project for biology classes.

- **Methods**

Determining which species to use in assessing the Gambles Mill Eco-corridor for mussel habitat consisted of reviewing previous literature on freshwater mussels, water conditions in LWC, and consultations with experts. Five criteria were used to evaluate and compare species for use in testing habitat and for a full restoration: 1) Availability of species, 2) Preferred habitats, 3) Filtration rates, 4) Fish hosts present, and 5) Stress tolerance.

1. **Availability of Species**

What species that the university could acquire for this project is limited by the availability of mussels from hatcheries and regulations regarding release of musses into the wild. There are 19 known species of mussels in the James River watershed (Jones 2015). Not all of them are commercially available because they are at risk and therefore are too valuable for experimental projects. The most convenient source of mussels is the Harrison lake Fish Hatchery located in Charles City, VA, which is a US Fish and Wildlife Service facility. (US Fish and Wildlife Service 2019). After consultation with them by phone, it was recommended that one of the two species *Pyganodon implicata* (Alewife Floater), or *Elliptio complanata* (Eastern elliptio) be used. Therefore, further research was limited to these two species.

## 2. Preferred habitats

There is a great variety in the geologic conditions in Virginia's Atlantic watersheds, which has given rise to a variety of species adapted to specific benthic and streambed conditions (Jones 2015). The preferred benthic habitat for *P. implicata* ranges from sandy to small pebbles (NaureService 2019). The preferred habitat for *E. Complanata* consists of streambeds composed of clay and fine sand (Mulcorone 2006). Both conditions are present in the Eco-Corridor, although a sandy bottom appears more prevalent than stony. (George 2019, Joireman 2019). Based on this information, *E. Complanata* was judged slightly more likely to be suited to the benthic habitat of LWC than *P. implicata.*

## 3. Filtration Rates

Most previous research indicates that there is little significant variation in filtration rates between freshwater mussel species, and even little between freshwater and saltwater mussels (Cheng & Kreeger 2017). However, there is considerable variation in filtration rates due to the stream conditions. The main factors in determining the capacity of mussels to filter water are the temperature, seston (organic particles) composition, and population size. Most water clearance rates for mussels range between 0.5 and 1.5 liters per hour per gram of dry tissue (Cheng &

Kreeger 2017). Because of this lack of difference in filtration rates between species, it was decided that there was no clear choice between the two species based on filtration rates.

**4. Fish hosts**

In the juvenile stage of their life cycle, most freshwater mussel species rely on fish as parasitic hosts. Larval mussels live in the gills for up to several weeks and depend on fish for dispersal, which is a characteristic unique to freshwater bivalves (Jones 2015). Many streams that lost their mussel populations have experienced sufficient water quality improvements to hold mussels again, but do not because the necessary fish species are missing (Gray & Kreeger 2013). Therefore, identifying what, if any, fish present in the LWC that are compatible hosts for mussel species is critical for the success of any full restoration.

As part of the Gambles Mill Eco-Corridor restoration, a survey of the number and species of the fish was conducted. As seen in (table 2), *E. complanata* is known to have widemouth bass and American eel as host species (Mulcorone 2006, J. Ryan, personal communication, November 19, 2019). Both of these species have been seen in the LWC, indicating that the E. elliptio would be able to reproduce and establish a population. *P. implicata* is known to be compatible with the Blueback herring (J. Ryan, personal communication, November 19, 2019). This species had not been seen in the LWC, indicating that *P. implicata* would have difficulty in establishing a population. However, most of the known mussel host species identified in the LWC have not been seen in post-restoration surveys (Joireman 2019). Therefore, it highly unlikely that a large-scale restoration would succeed in establishing a stable population until these species return. Based on this information, it was decided that *E. complanata* would make a better species to use for a long-term restoration.

## 5. Stress Tolerance

Because the purpose of using caged mussels as a first step of a restoration would be to test the water quality for mussels, the sensitivity of the species used to various parameters is important to consider. Part of what this research seeks to address and add to the literature is discerning the water quality factors that are most critical for mussel habitat. While it is known that important parameters include the nitrogen and phosphorous contents, water flow, and benthic composition to name a few, the exact ranges that make for good habitats are generally unclear and has led to low success rates for restoration efforts (Gray & Kreeger 2013).

Information provided by the Harrison Lake Fish Hatchery indicated that *P. implicata* is slightly more tolerant of various water conditions with a wider range of habitats. (US Fish and Wildlife Service 2019). However, *E. complanata* has also been used in similar test cage studies in a variety of habitats (Gray & Kreeger 2013). Therefore, there was no clear choice between species based on this criterion.

Overall, there was little difference between *P. implicata* and *E. complanata*. The only major definite difference was in the host species observed in the LWC. Therefore, it was predicted that *E. complanata* would be species better suited for restoration in the Gambles Mill Eco-Corridor (Table 3).

**Table 2:** Fish Species Identified in Little Westham Creek (Joireman 2019)

| **Common Name** | **Scientific name** | **Count 9/29/19** | **Count 10/25/19** | **Mussel Species** |
|---|---|---|---|---|
| Yellow Bullhead | *Ameiurus natalis* | 5 | 0 | N/A |
| American eel | *Anguilla rostrata* | 1 | 0 | *E. Complanata* |
| Pirate perch | *Aphredoderus sayanus* | 9 | 0 | N/A |
| Tessellated darter | *Etheostoma cordata* | 9 | 0 | N/A |
| Eastern mosquitofish | *Gambusia holbrooki* | 9 | 5 | N/A |
| Green Sunfish | *Lepomis cyanellus* | 2 | 0 | N/A |
| Green Sunfish | *Lepomis cyanellus* | 1 | 0 | N/A |

| | | | | |
|---|---|---|---|---|
| Pumpkinseed | *Lepomis gibbosus* | 2 | 0 | N/A |
| Warmouth | *Lepomis gulosus* | 2 | 0 | N/A |
| Bluegill | *Lepomis macrochirus* | 105 | 9 | N/A |
| Largemouth Bass | *Micropterus salmoides* | 12 | 5 | *E. Complanata* |
| Bluntnose Minnow | *Pimephales notatus* | 110 | 0 | N/A |
| Spotfin Shiner | *Cyprinella spiloptera* | 75 | 0 | N/A |
| Central Stoneroller | *Campostoma anomalum* | 1 | 0 | N/A |

**Table 3:** Suitability of species in regards to parameters considered. S = suited, NS = not suited.

| | *P. Implicata* | *E. Complanata* |
|---|---|---|
| Availability of Species | S | S |
| Preferred Habitats | S | S |
| Filtration Rates | S | S |
| Fish Hosts | NS | S |
| Stress Tolerance | S | S |

- **Relation to past research**

Restoration projects of freshwater mussels have met with difficulty and unpredictable results because of a lack of clear knowledge of the exact water chemistry that make up habitats that mussel require. There is indication that frequent failure of mussel restorations is, "due in part to an inability to identify suitable habitat for these organisms" (Gray & Kreeger 2013). What knowledge exists for mussel habitats primarily relates to ocean mussels, which have been the subject of more research to date (Hoellein et al. 2017). The use of small, contained samples of mussels as in-situ bioindicators to test water quality has been previously researched and promoted as a way of improving the success rate of mussel restorations (Cheng & Kreeger 2017, Gray & Kreeger 2013, Nobles & Zhang 2019). These techniques form the primary basis for the research project suggested here.

- **Suggested steps in implementing test cages:**

I recommend the following process to the university for implementing a test cage research project. This is by no means an exhaustive list and is meant to serve as a guideline for more precise panning.

**1. Obtain Fish collection permit**

To introduce mussels to the LWC, the university will need to apply for a Fish Collection Permit from the Dept. of Game and Inland Fisheries for *E. complantana.*

**2. Source mussels**

Mussels should be obtained from the Harrison Lake Fish Hatchery as they are one of the closest locations that can supply mussels.

**3. Cage designs**

There are two common designs for mussel cages that could be used: Wire cages and mussel silos. The wire cage design has been used by Gray & Kreeger for similar projects testing mussel habitats with live specimens (2013). These cages can be easily constructed from wire racks and mesh. The mussel silo design is constructed from concrete with a cylindrical chamber to hold the mussels. This design is far less likely to become dislodged and wash away, although it is more difficult to construct. Both designs could be constructed on campus and are relatively inexpensive. (J. Ryan, personal communication, November 19, 2019, US Fish and Wildlife Service 2015).

**Figure 2:** Mussel Silo designs (US Fish and Wildlife Service 2015)

4. **Instillation process**

The instillation of test cages should happen in late spring or early summer during good conditions for mussels (Jones 2015). This could be done either by paid professionals or by students and part of a research project.

5. **Monitoring process**

In order to obtain data regarding the suitability of the LWC for a full mussel restoration, regular monitoring of the mussels and water quality would be needed. Monitoring should take place for at least a year to obtain accurate seasonal data on mussel habitat and filtration capacities. Although the exact parameters that should be measured can be determined during further planning for implementation, there are several that should be included. Several parameters included in other studies on mussels include seston metrics such as particulate matter, organic content, and protein content (Cheng & Kreeger 2017). Parameters to include for measuring the health of mussel populations include shell lengths, weight, and survival rates. (Hoellein et al. 2017). Some techniques involve measuring the dry weight and biochemical content of the mussels themselves, including protein, carbohydrate, and lipid content. This provides a far better indication of long-term stress than simple mortality and is a better indicator of habitat overall (Gray & Kreeger 2013). However, these measurements are not recommended until the end of the monitoring period. The rate of excretion and biodeposition should also be monitored to obtain more accurate estimates for the effects of a full restoration. This would involve placing musses in containers of filtered water and measuring what they excrete over time. A process similar to that described in (Hoellein, Zarnoch, & Grizzle 2015) for measuring mussel biodeposition rates may be suggested.

- **Costs – Test Cage Materials**

One of the major factors for the University to consider in such a testing project would be the costs of instillation and monitoring. As one of the long-term goals would be to have biology classes carry out the monitoring as physical lab, the monitoring costs are expected to be minimal. The final costs of material needed for the instillation of the project range from 60 to 200 dollars per cage, with four or five cages used in total. Mussels from the Harrison Lake Fish Hatchery cost between 2 and 3 dollars per mussel (US Department of Game and Inland Fisheries 2019). Total costs for materials range from an estimated 400 to 810 dollars, depending on the design used. See (Table 4) for a full breakdown of costs.

- **Effectiveness**

If testing proves to indicate that the conditions are favorable for mussels, then the amount of pollutants that stand to be removed must be accounted for. It is estimated that in a healthy environment, one hectare of mussels can filter up to 10 tons of total suspended solids, including 400 lbs of nitrogen, per year. Most filtration rates observed range from 0.5 to 1.5 Liters of water per hour per gram of dry weight mussel tissue, with an average of approximately 1 L/hour/g. Mussel population densities have a wide range depending on the local habitat and benthic substrate, ranging from 4-20 mussels per $m^2$. This averages out to approximately 100,000 mussels per hectare of good habitat, or 1000 to 100,000 mussels per mile of steam. (Cheng & Kreeger 2017). The calculations for the total amounts of nutrients removed are shown in (Table 5). It is estimated that approximately 2.5 tons of TSS and 100 lbs (dry weight) of nitrogen could be removed per year if the Gambles Mill Eco-Corridor was fully stocked with mussels.

**Table 4:** Total Costs for Mussel Test Cages

| **Items** | **Wire Design** | **Silo Design** |
|---|---|---|
| Mussels ($) | 2-3 | 2-3 |
| Musslels per cage | 50 | 10 |
| Materials per cage ($) | < 50 | < 30 |
| Cost per cage ($) | 200 | 60 |
| Tools/Equipment ($) | < 10 | < 160 |
| Number of cages | 4 | 4 |
| Total Cost, max ($) | 810 | 400 |

**Table 5:** Estimated amount of pollutants removed (assuming a robust population)

| | |
|---|---|
| Mussels per mile of stream | 1,000 to 100,000 |
| Length of Eco-Corridor | 0.58 miles |
| Filtration Rate | 10 tons TSS and 400 lbs of nitrogen per 100,000 mussels per year |
| Result: (assume 50,000 mussels) | 5 tons of TSS and 200 lbs of Nitrogen/year |

## Final discussion:

Literature on the subject of freshwater mussels and information on the Gambles Mill Eco-Corridor suggest that there is little overall measurable difference between the species *E.complanata* and *P. implicata*. The only significant difference between them was in fish species observed, which clearly favored *E.complanata* as the better species to use in a long-term mussel restoration. This partially supported the hypothesis that there would be one species better suited to the habitat in the LWC. Therefore, I recommend that should the University of Richmond consider exploring further options for a full mussel restoration, that they deploy test cages with *E.complanata* mussels to determine the suitability of the habitat in the Gambles Mill Eco-Corridor. I also note that while it may be possible to deploys test cages relatively soon, it may take some time until a full restoration can be attempted because of the time needed for fish to return. Although the water pollution goal of the Gambles Mill Eco-Corridor restoration is to remove 1,140 lbs of total phosphorus, the estimated 200 lbs of removed nitrogen per year provided by mussels is not insignificant (Joireman 2019). Monitoring any tests cages could provide a valuable teaching experience for biology classes and could potentially provide additions to the literature on positive conditions for mussel restorations, which is currently lacking. Finally, restoring native mussel species would promote the full development of the aquatic ecosystem in the LWC and assist in restoring them to their historic range.

**Literature Cited:**


Cheng, K. M. & D. A. Kreeger. (2017). “Determination of Filtration Capacity and Pollutant Removal of Freshwater Mussels in Delaware Streams.” Partnership for the Delaware Estuary, Wilmington, DE. PDE Report No. 17-04.

Gray, M., Kreeger, D. (2013). “Monitoring fitness of cages mussels (Eliptio complanata) to assess the prioritize streams for restoration.” Aquatic Conservation: Marine and Freshwater Ecosystems. 24, p. 218-230.

George, E. (2019). “Impact of Stream Restoration on water quality: Water Quality of Little Westham Creek Post-Restoration." Paper for Environmental Studies Senior Seminar/Geography Capstone, University of Richmond, December 2019.

Hoellein, T., Zarnoch, C., & Grizzle, R. (2015). “Eastern oyster ( Crassostrea virginica) filtration, biodeposition, and sediment nitrogen cycling at two oyster reefs with contrasting water quality in Great Bay Estuary (New Hampshire, USA).” *Biogeochemistry*, *122*(1), 113–129. https://doi.org/10.1007/s10533-014-0034-7

Hoellein, T., Zarnoch, C., Bruesewitz, D., & DeMartini, J. (2017). “Contributions of freshwater mussels (Unionidae) to nutrient cycling in an urban river: filtration, recycling, storage, and removal.” Biogeochemistry, 135(3), 307–324. https://doi.org/10.1007/s10533-017-0376-z

Joireman, M. (2019). “Gambles Mill Eco-Corridor. Univeristy of Richmond.” Available https://urichmond.maps.arcgis.com/apps/MapSeries/index.html?appid=2a4bc41dbe444157a1bb1ece4687b49a#

Jones, J. W. (2015). “Freshwater Mussels of Virginia (Bivalvia: Unionidae): An Introduction to Their Life History, Status and Conservation” Virginia Journal of Science. 66(3).

Mulcrone, R. (2006). "Elliptio complanate." Animal Diversity Web. Accessed December 03, 2019 at https://animaldiversity.org/accounts/Elliptio_complanata/

Natureserve. (2019). NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available http://explorer.natureserve.org. (Accessed: December 3, 2019 ).

Nobles, T.,Zhang, Y. (2015). “Survival, Growth and Condition of Freshwater Mussels :Effects of Municipal Waste water Effluent.” PLoSONE10(6): e0128488.doi:10.1371/journal.pone.0128488

Ray, N. E., Li, J., Kangas, P. C., & Terlizzi, D. E. (2015). “Water quality upstream and downstream of a commercial oyster aquaculture facility in Chesapeake Bay, USA.” Aquacultural Engineering, 68, 35–42. https://doi.org/10.1016/j.aquaeng.2015.08.001

Reidl, D. (2019.) Water Quality Results, University of Richmond - Westhampton Lake. SOLitude Lake Management.

US Fish and Wildlife Service. (2015). “Cedar River Mussel Biomonitoring.” https://www.fws.gov/midwest/RockIsland/ec/Research/CedarRiver/biomonitoring.html

US Fish and Wildlife Service. (2019). “Harrison Lake National Fish Hatchery.” https://www.fws.gov/harrisonlake/index.html