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# Effects of Bridge Sites on Freshwater Mussel Community Structure and Density

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EFFECTS OF BRIDGE SITES ON FRESHWATER MUSSEL COMMUNITY STRUCTURE AND DENSITY

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## Abstract

Freshwater Mussels (family Unionidae) are one of the most imperiled group of species found in the United States. Much of this is due to anthropomorphic changes made to their environments. Mussels depend on host fish for their unique parasitic reproductive cycle, therefore environmental factors that affect fish also affect mussels. Construction activities in and near water play a role in impacting freshwater ecosystems. Bridges under construction can affect sedimentation rates and local deposition, as well as the hydrologic flow of the stream. Since mussels are protected in Ohio, surveys must be done prior to bridge construction to determine the impact of the project on mussel resources. Our study used data from survey reports conducted in Ohio from 2013-2019 at bridge sites. We organized the data to determine mussel community structure and density directly underneath bridges compared to away from bridges. We found the average live mussel density underneath a bridge was 0.42 mussels/meter$^2$ while away from bridges was 0.19 mussels/meter$^2$ ($T$=1.99, $P$=.05). We calculated the species richness underneath bridges compared to the outside and found no significant difference ($T$=1.98, $P$=.08). However, we discovered that 78% of the mussel species reported in these reports preferred to live underneath bridges. The tendency to be under the bridge was further emphasized when we compared mussel density at the species level directly underneath the bridge and in the reach identified as the Area of Direct Impact located immediately outside of the bridge. We discovered that all mussel species, except *Pluroblema sintoxia* (round pigtoe) preferred to be underneath a bridge ($T$=1.99, $P$=.01). Our findings support the conclusion that bridges create a preferred environment for freshwater mussel species. Bridges may also create a preferred environment for their host fish species as well, but further research on fish distribution and stream composition would be necessary to support this conclusion.

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## Introduction

Freshwater mussels (*Bivalvia: Unionidae*) are essential filter feeders involved in maintaining the water quality in freshwater ecosystems. Worldwide there are 890 known mussel species, and 300 of those live in North America. Of the 300 species, 20% are on the brink of extinction. This decline is mostly apparent over the last 25 years and continues to progress exponentially. Freshwater Mussels are a valuable part of the food web, improve water quality, and are indicator species (Jepsen et al. 2010). Mussels spend a majority of their lives as stationary filter feeders and are found attached to substrates or burrowed beneath the sand in shallow, cool, or moving waters. They filter water through their gills to retrieve bacteria, protozoans, and other organic particles for food, while also filtering debris out of the water to make the environment better for other organisms. They are susceptible to many pollutants and contaminants, meaning the presence or absence of them in bodies of water, as well as analyzing their shells and tissues, can indicate the water quality (Dickson et al. 2016). The instability of mussels entailing their population structure and abundance can change drastically due to environmental impacts. The loss of mussels from bodies of water therefore will result in negative consequences to ecosystem function and the aquatic community (Khaitov, 2012).

Freshwater mussels are a group of molluscs with a unique reproductive life cycle (Fig. 1). Mussel larvae are called glochidia, which are parasites on fish. The method of host fish infection varies among mussel species. A few of these methods may entail releasing glochidia to freely float in the water until a host fish swims by, creating a lure to attract a fish, or releasing glochidia into the water that look like fish food. Once glochidia are released, they attach to the gills or fins of the host fish and encyst to complete development (Charters et al. 2001). The movement of their host fish during the parasitic stage is important for mussels' large-scale dispersal

(Burlakova et al. 2017).  After metamorphosis on the fish host, juvenile mussels drop off and can be further dispersed through drifting. After a juvenile drops off of the host, the location on the streambed where it eventually rests depends on the velocity of the juvenile as well as the current velocity and streambed topography (Irmscher and Vaugn, 2018). The distribution distance may also vary depending on the type of host fish and what type of waters it prefers to live in. Flow patterns and high velocities may influence the dispersal. However, the parasitic mussel may have effects on the host fish behavior, resulting in reduced stamina and seeking out slower flowing water which will impact the distribution as well. Overall, fish are important to the distribution of mussels because as sessile organisms, the mussel larvae are unable to disperse far on their own. (Daraio et al. 2012).

Ecosystems consist of many animals that have top-down effects through consuming resources and bottom-up effects when excreting and egesting nutrients. Specifically looking at the relationship between fish and mussels, their different life histories influence how their distribution varies in the environment (Badra, 2017). Mussels are long-lived and spend their adult lives in mussel beds, which are patchily distributed because mussels are limited to perennial reaches where there are stable sediments and low stress. Meanwhile, fish are short-lived, mobile animals where their distribution and abundance relies solely on hydrology. The distribution of fish therefore shifts seasonally because it depends on hydrology, while mussels are more stable (Hopper et al. 2018). It is known that different mussel species require different habitats, and the availability of the specific habitat affects their distribution (Newton et al. 2008). A study done by Inoue et al. (2017) focused on the biotic and abiotic factors with mussel and fish distribution. They found that the presence of fish hosts does not likely predict mussel presence riverwide, meaning that abiotic conditions are the main factors which explain the co-occurance of mussels and fish hosts together. In general it was found that they shared abiotic responses, however a few mussels-fish host pairs had different abiotic responses such as their sensitivity to eutrophication. These variabilities may affect whether a mussel is a generalist or specialist in regards to choosing a fish host species.

Construction activities have the potential to change erosion patterns, sediment deposition, substrate composition, and local hydrology, which can negatively affect the mussel populations. About 19% of the United State's total land area is impacted by the public road system. Road construction is one of the major nonpoint pollution sources and highway construction has many short and long term effects on stream conditions (Chen et al. 2009). Major contributors to the degradation and loss of mussel habitat include water flow alterations associated with channel modification and hydrologic changes to watersheds. Water flow patterns can be altered by irrigation diversions, dams, channelization, and groundwater pumping, all of which have caused deaths of 30 to 60 percent of freshwater mussel species in many U.S. rivers.

Damming has a large impact on mussel and fish host species. It can transform waters into becoming stagnant, which entails heavy silt deposition and less oxygen. The high water velocities from dams can also displace young juvenile mussels who are not strong enough to bear it, as well as kill or impair mussels if the water is too low for an extended period of time. The distance mussels are from dams have been found to impact their community composition entailing a decrease in species richness and abundance the closer they are to the dam (Burlakova et al. 2016). However, dam removal is becoming more popular in order to restore river habitat. Although the large amount of sediment built up behind the dam will have the potential for downstream deposition, this is a short term affect. It is typically believed that the long term benefits of reconnecting populations outweigh those short term costs (Hogya and Andrikanich, 2017). Water modifications can also interfere with mussel's host fish species due to the changes in temperature, velocity, and depth of the water. As a result, fish may not live in the area anymore, or be prevented from dispersing from upstream to downstream due to the barrier the dam creates. This results in reduced gene flow of freshwater mussels because they will be unable to travel far. The modification of the environment for human purposes therefore affects the likelihood of freshwater mussel survival (Dickson et al. 2016).

Bridges are a prime example of a negative human impact that can play a role in affecting mussel populations (Fig. 2). These structures can create eutrophication which will affect water flow over mussel beds, reducing their feeding abilities and oxygen supply. As well, ecessive amounts of sediment washing into the water from bridge construction can essentially form a hardpan layer, thus reducing interstitial flow rates (Environment Agency, 2002). Cao et al. (2016) focused on bridge abutements and their impacts on macroinvertebrate communities and found that riverbank ecosystem degradation entailing sediment deposition and scours have an impact on the macroinvertebrate community structure and diversity. However, a study done by Combs et al. (2011) looked at culvert and bridge impacts and found that neither of them accumulated enough sediment to impact fish species. Scour was found at all of their studied bridge sites, which decreases bridge stability. Local scour around pillars is a result of altered flow which causes an increase in sediment transport capacity. These have little impact on the overall community, but scour pools can create an enhanced habitat for fish. There are options in which to minimize the impacts on the environment when conducting maintence or construction on pre-existing bridges. These solutions may entail top-down demolition/construction to help with minimizing sedimentation and maintaining stream flow (Charters et al. 2001). However, bridges themselves are a reduction in cross sectional area for water flow, which may lead to increases in stream velocities to levels which smaller fish cannot swim upstream in (Vander Pluym, 2006).

Transportation agencies primary jobs are to develop the nation's infrastructure. However, preserving natural resources is an important factor they must follow when doing so. When an intitial project is proposed, an environmental assessment must be conducted before the project can begin in order to assess any environmental impacts it may have on the surrounding habitats. For freshwater mussels, surveys are essential in determining whether the project site entails a mussel population. If they are found present, they must be moved (relocated) to minimize the impact. The construction activities previously mentioned, show the importance of implementing mussel surveys for projects with these impact risks to prevent harming the present mussel populations (Dickson et al. 2016).

The relocation of mussels for bridge site projects is important in order to remove them from any threat they may face if they were to stay. This effort is set into place by state and federal wildlife agencies which require mitigation when mussel species are present at a construction site. The area in which mussels are removed is typically in the designated area of impact zone. This zone is "the area of potentially disturbed substrate, zone of heavy equipment operation, and the distance downstream that may experience sedimentation". Though relocations are frequently done, there are still unknowns in regards to the best methods for removing mussels from the site, relocation timing, handling and transportation of individuals, habitat criteria for the relocation site, post-relocation monitoring methods, and growth and survival. Once these topics are intensely studied, the effectiveness of mussel relocations will drastically increase to our awareness (Dickson et al. 2016).

Bridge construction sites are the most common sites in which mussel surveys are conducted. During construction, the substrate underneath the bridge typically experiences a high level of sedimentation, which is one of the major impacts on freshwater mussels. Sedimentation practically buries mussels, leaving them no way to breathe or escape. This is the primary reason why mussels are removed and relocated before constuction begins. The area underneath a bridge during construction will be completely free of mussels after the survey relocation is done. However, this relocation process unintentionally begins a natural repopulation experiment underneath the bridge. Over time, after the bridge is worked on, the mussels (with the help of host fish) move back underneath the bridge (Dickson et al. 2016).

The objective of this study was determine the impact bridges have on mussel abundance and distribution. There is evidence regarding the environmental changes a bridge site can have on the habitat underneath the bridge (Combs et al. 2011). Our study hypothesizes that mussels will have higher densities directly underneath bridges due to their preference of the habitat created underneath. As well, we hypothesize that the community structure will be positively impacted by the area underneath a bridge and will support more species than in the immediate vicinity of the bridge. If we discover that mussels are found distributing more abundantly underneath bridges then this finding may alter how mussel surveys are done in the future. If significant data are found supporting our hypotheses, then further research can be done in relation to host fish presence, watershed identity, and environmental variables for directly underneath and outside of bridge sites (Cottenie, 2013).

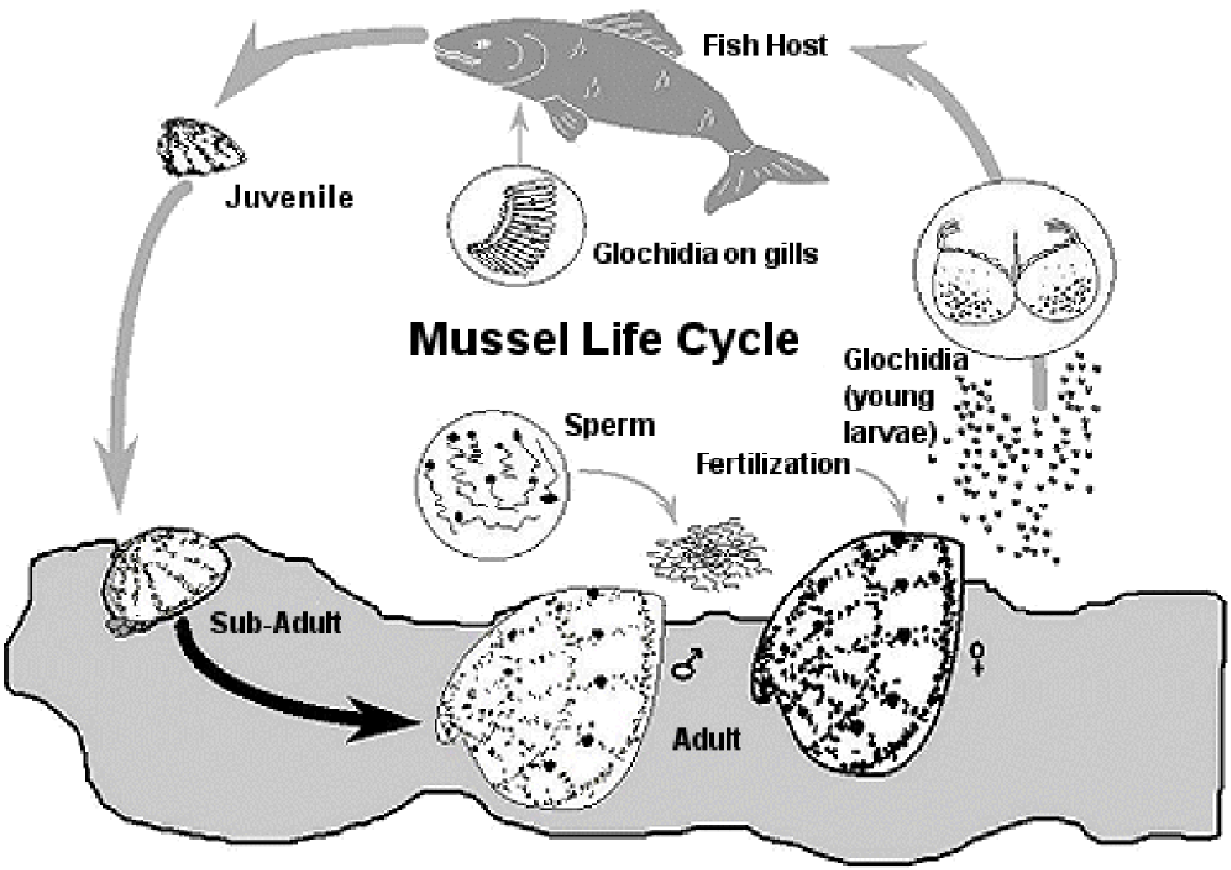
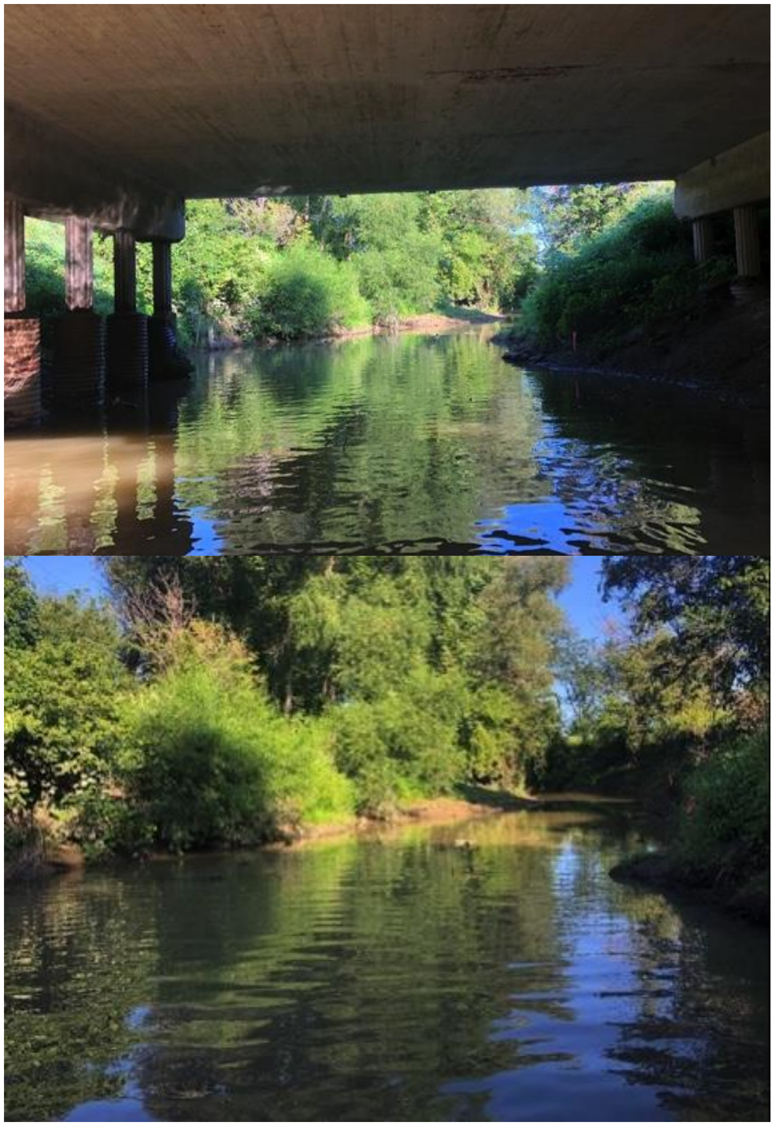



Figure 1. Life cycle of Unionids.



A.)

B.)

Figure 2. A.) Viewing beneath the existing bridge within the Area of Direct Impact (Jerome Fork). B.) Viewing the Upstream Buffer area from the Area of Direct Impact (Jerome Fork).

## Materials and Methods

*Survey Protocols*

In this study we analyzed freshwater mussel survey reports that the Ohio Department of Transportation (ODOT) requires to be completed for roadway bridge construction projects. We used reports conducted during the years of 2013 through 2019. All surveys were done by approved surveyor companies or by ODOT itself. Every company followed the same protocols while surveying. The Ohio Division of Natural Resources (ODNR) and U.S. Fish and Wildlife Services (USFWS) according to 2018 standards, require mussel survey biologists to divide streams at bridge sites (for bridges being replaced or new structures) into three reaches of stream. These reaches include a downstream buffer of 25 meters that extends the entire width of the stream, an area of direct impact extending the entire length of the impact area (usually to the limits of right-of-way) that includes the reach of stream beneath the bridge, and an upstream buffer of 10 meters. Each of these reaches is then subdivided into areas no larger than 100  for sampling of the mussel community (Fig. 3). These data are recorded along with their position relative to the bridge. Surveys done before 2018 that were used in this study still followed the same standards of sampling in cells.

*Reports Analysis*

A total of 45 different reports and locations were analyzed in this study (Fig. 4). We found background information for each report which included the survey date, surveyor company, location, and stream name (Appendix II). For each survey, we took information and organized it into an excel file consisting of each cell name, cell size, mussel species name, it's category (species of concern or threatened), its condition (live or dead), the quantity of the species found in each surveyed cell, and the cells location in the stream. The locations in the stream were labeled either as downstream, in the area of direct impact, upstream, and also if it was underneath the bridge.

Most reports did not denote if a mussel was found beneath a bridge, therefore figures that were provided in the reports were used to help determine if cells were underneath a bridge. If a cell was halfway underneath a bridge, then half of the mussels found in that cell were considered underneath the bridge. If no figure of the survey cells was provided in the report, then we manually made one on Google Earth by using the provided dimensions from the report to determine where the cells were located in relation to the bridge. Information on the stream survey area was also compiled by including the length and width of each reach, the total size of area surveyed, and the area underneath the bridge. If the width of the reach was not stated, the survey location was found in Google Earth and measured using the ruler tool. Bridge widths were also measured using the same technique. The area of water found underneath the bridge was calculated by multiplying the width of the bridge with the width of the stream. The total survey area was also calculated the same way if it was not provided in the report.

All surveys were done by using the cell method, however not every report provided the cell sizes. In those situations, the report was still divided into segments such as 0-10 meters downstream, 10-20 meters downstream, etc. Therefore, the length of the stream surveyed was then multiplied by the width of that area of stream in order to distinguish the area of each "cell" that mussels were found in.

Many reports only provided information on where mussels were found in the stream (upstream, ADI, or downstream) and did not specify what cell or distance downstream they were found. These reports were not included in the study due to their lack of clarification on the locations. We decided to go with reports with at least ten live mussels because we were interested in explaining mussel diversity and we determined that reports with fewer than ten mussels do not constitute a diverse mussel community. We also chose to look at the statistics with live and dead mussels together, and then live-only mussels due to the fact that the dead shells may have drifted towards the areas and were not actually stabilized into the stream bed.

*Statistical Analysis*

We first compiled data to determine the community structure of mussels at each location, and then each location was combined to reach an overall conclusion. For each survey, the total number of individual species was totaled and sorted into whether they were found underneath a bridge or outside. They were also sorted into which reach of stream they were found; either downstream, upstream, or in the ADI. The numbers found in each survey were then combined to conclude an overall finding. Densities of mussels were found for each cell by dividing the number of mussels found by the size of the cell. The total density of mussels found beneath a bridge and outside a bridge was also calculated, then combined with all other surveys for an overall conclusion. The densities were also sorted into reaches of stream; downstream, upstream, or in the ADI. To determine species richness in each stream, the mussels in each survey were sorted by the total number of different species found, as well as the total species in the specific reaches of stream (downstream, upstream, ADI, or underneath bridge). All of these calculations were done with live and dead mussel data, as well as with live-only mussel data.

To determine whether there was a significant difference between where mussels prefer to settle, the mean and 95% confidence interval were calculated for each location on the mussel densities. After calculation of the average, a descriptive statistical analysis was conducted on Microsoft Excel. Based on the different location means, a two tailed paired student t-test was calculated and was used to determine the differences in each location when compared to one another. The mussel community data was calculated for each mean per species to determine where they were most likely to be found by comparing their densities. Species richness was calculated by a two tailed paired student t-test between the species underneath bridges and those found outside of bridges.

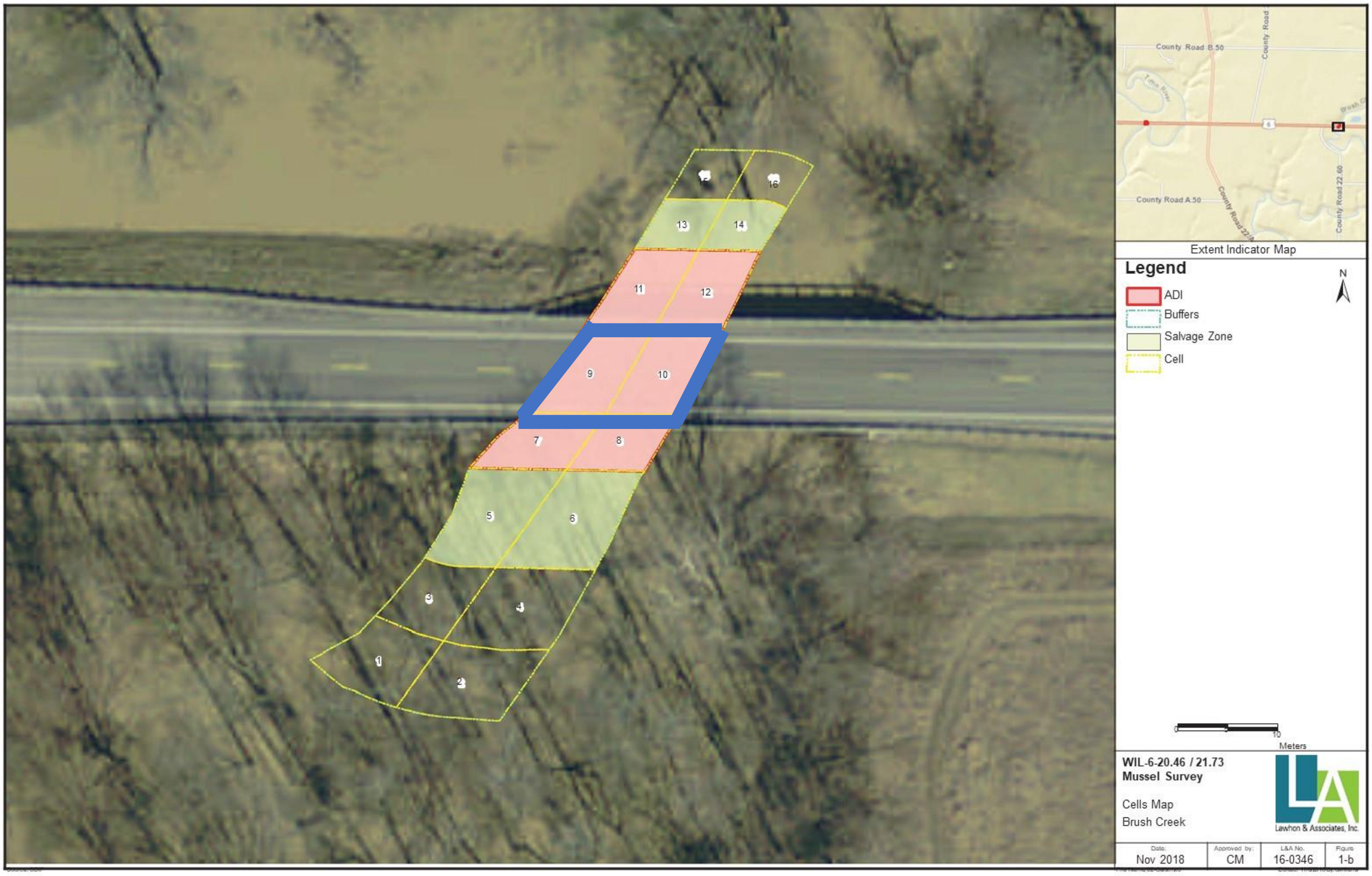



Figure 3. A typical survey layout divided by cells. Cells are labeled and arranged from Downstream (1-6), Area of Direct Impact (7-12); with includes cells under the bridge, and Upstream (13-16). The thicker line is the area that was depicted as the area underneath the bridge (9-10).

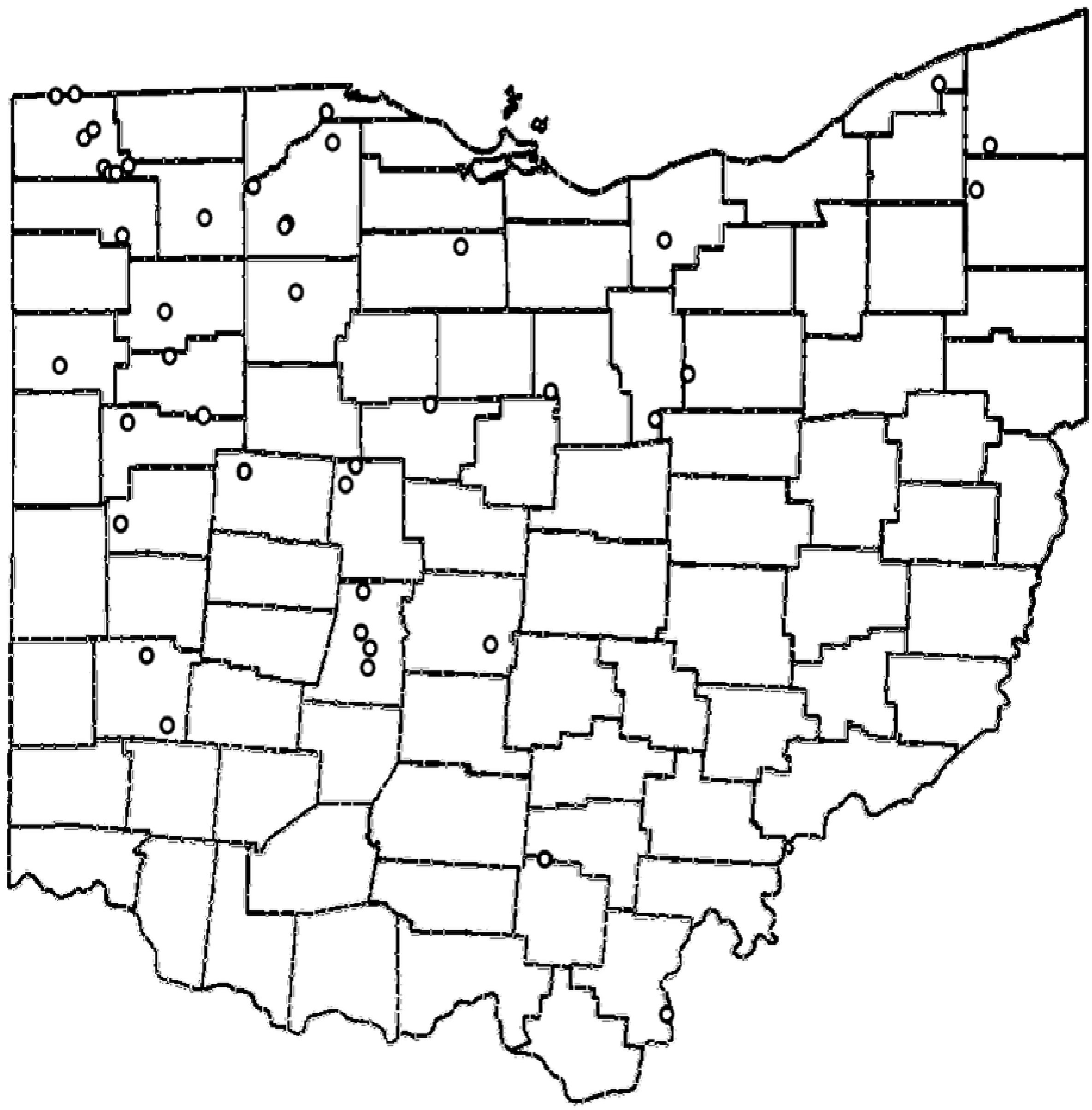


Figure 4. A Map of the 45 survey locations conducted in Ohio from 2013-2019.

**Results**

*Mussel Abundance and Density*

A total of 8,144 mussels were found in the 45 surveys. There were a total of 7,957 live and 187 dead. Of the total number of live and dead individuals 2,443 were found underneath a bridge and 5,701 were found outside of a bridge. Out of live-only individuals 2,371 were found underneath a bridge and 5,586 were found outside a bridge. The average density calculated for live and dead found underneath the bridge was 0.4223 mussels/meter$^2$ , while outside of the bridge was 0.1937 mussels/meter$^2$ (Table 1). A significant difference was found between the data ($T$=1.99, $P$=.049). The average density calculated for live-only underneath the bridge was 0.4207 mussels/meter$^2$ , while outside of the bridge was 0.1945 mussels/meter$^2$. A significant difference was also found between these data ($T$=1.99, $P$=.05). Significance was also found in live and dead, and live-only data when comparing the density in the ADI directly underneath the bridge to the ADI located outside the bridge (Live and Dead: $T$=1.99, $P$=.02 Live-only: $T$=1.99, $P$=.01). The densities of mussels found 10 meters and 20 meters upstream and downstream of the bridge were calculated. These findings concluded to have no significant difference when compared to directly underneath the bridge for 10 meters ($T$=2.03, $P$=.12) or 20 meters away ($T$=2.04, $P$=.11).

*Species Richness*

Species richness entailed a total of 32 different species in the surveys (Appendix III). On average, 4.36 live and dead species were found underneath bridges in a typical report while 5.56 were found outside of bridges. Statistically there is no significant difference when comparing the two averages ($T$=1.98, $P$=.08). For live only, 4.11 were found underneath bridges and 5.38 were found outside of bridges. Statistically there is no significant difference as well when comparing the two averages ($T$=1.98, $P$=.06).

*Community Structure*

Community structure of the 32 different species was only collected with live mussels (Appendix III). The most abundant species found was *Pyganodon grandis* (giant floater), with one of the higher densities underneath bridges (0.13). However, *Actinonaias ligamentina* (mucket) had the highest density underneath bridges (0.38) while it was only the 13$^{th}$ most abundant. There were 7 species which had higher densities outside of bridges than directly underneath bridges. Densities of each species was also calculated under the region of ADI not underneath the bridge (Appendix IV). These findings show that the densities of the ADI underneath the bridge were higher for all species (except *Pleuroblema sintoxia*, round pigtoe) than the densities of the ADI outside of the bridge area.

Table 1. Statistical values to determine significance in the data comparisons between the density (mussels/meter$^2$) underneath the bridge and +/- 10 m, +/- 20 m, the ADI not underneath the bridge, and the entire area outside of the bridge (p=0.05). Species richness was also compared between underneath and outside of the bridge (p=0.05). The bolded numbers are the significant values.

| **Distance from Bridge** | **Live & Dead** | | **Live Only** | |
|---|---|---|---|---|
| | **Density Under Bridge** | **Species Richness Under Bridge** | **Density Under Bridge** | **Species Richness Under Bridge** |
| **+/- 10 m** | p=0.1739 | | p=0.1204 | |
| | t=1.9944 | | t=2.0301 | |
| **+/- 20 m** | p=0.1863 | | p=0.1020 | |
| | t=1.9996 | | t=2.0369 | |
| **ADI Not Under Bridge** | **p=0.0112** | | **p=0.0108** | |
| | t=1.9925 | | t=1.9960 | |
| **Outside of Bridge** | **p=0.049** | p=0.0780 | **p=0.0508** | p=0.0636 |
| | t=1.9978 | t=1.9886 | t=1.9983 | t=1.9890 |

Table 2. Data including the average density (mussels/meter$^2$), standard deviation and 95% confidence interval of mussels in the ADI outside of a bridge, underneath a bridge, outside of a bridge, +/-10 m and +/- 20 m from a bridge.

| Average | Condition | Average Density | STDV | 95% |
|---|---|---|---|---|
| **ADI Outside Bridge** | Live | 0.1161 | 0.3890 | 0.1078 |
| | Live and Dead | 0.1182 | 0.3889 | 0.1078 |
| **Under Bridge** | Live | 0.4207 | 0.7222 | 0.2002 |
| | Live and Dead | 0.3694 | 0.6653 | 0.1844 |
| **Outside Bridge** | Live | 0.1945 | 0.3470 | 0.0962 |
| | Live and Dead | 0.1760 | 0.3207 | 0.0889 |
| **+/- 10 m** | Live | 0.2639 | 0.4299 | 0.0919 |
| | Live and Dead | 0.2274 | 0.3930 | 0.0840 |
| **+/- 20 m** | Live | 0.2513 | 0.3326 | 0.0922 |
| | Live and Dead | 0.2365 | 0.3849 | 0.0629 |

**Discussion**

*Mussel Abundance and Density*

The findings on mussel density underneath and outside of bridges have a statistical difference (*P*=.05). Most of the t-tests conducted had P values less than or equal to .05. It is important to note that the average area underneath a bridge was 235 $m^2$, while the average area outside of a bridge was 1220 $m^2$. The outside area was over five times the size of underneath a bridge, yet outside of bridges only had twice as many mussels than underneath a bridge. As well, the average density underneath a bridge was twice as much as the density outside of a bridge. Therefore, an observation that mussels seem to be preferring to live underneath bridges can be made and statistically supported. This may be due to host fish species being attracted to the water environment underneath bridges, which therefore links a possibility as to why mussels are underneath bridges. More research done on locations of host fish species found in streams would be beneficial for supporting this statement.

There are 12 reports which have a drastically higher density underneath the bridge than outside of the bridge area (over twice as much). This is further evidence in supporting the observation in which a bridge may be providing a different habitat which mussels seem to prefer. A future look into these survey  locations would be beneficial in order to determine what these locations may have in common with each other to help support these findings.

Looking at the densities of the ADI directly underneath the bridge compared to the densities of the rest of the ADI not underneath the bridge, there was a significant difference in the data (*T*=1.99, *P*=.011). This finding further supports that mussels prefer to live directly underneath bridges compared to areas right outside of the bridge. This reason may be that the bridge provides shade for individuals living underneath, or a preferred substrate that seems to accumulate underneath bridges but not directly outside of them. Further research on stream composition underneath and outside of bridges would be beneficial in determining if there is a statistical difference between the two areas. Value would be added to mussel surveys if their data could be aligned with stream assessment sites used by state agencies. The Ohio Environmental Protection Agency (OEPA) is one agency that monitors the interaction of chemical, physical and biological processes to assess the health of surface waters and their organisms. The OEPA also reports drainage area, qualitative habitat evaluation indexes (QHEI), fish community metrics (index of biotic integrity) and landuse. These biological assessment tools are used to determine the status of bodies of water in Ohio, but unfortunately do not include mussels. If these two reports are able to be compared to one another, then further connections could be made to determine reasons behind mussel densities and community structures (Begley and Krebs, 2017). Knowing that mussels have a higher density underneath bridges is beneficial to surveyors because mussels that fall within the ADI have to be relocated to another area. If it is shown that most mussels prefer to live underneath a bridge, then perhaps efforts can be taken to temporarily relocate them when construction is being done and then be reintroduced once it is finished. Research looking at whether mussels fair under temporary relocations in this way must be done before trying to take action.

*Species Richness*

The area outside of a bridge had a higher number of species than underneath a bridge. However, the area was also five times as large as underneath a bridge. According to the species-area curve, as the area gets bigger so should the number of individuals and species. Therefore, if you were to compare the sizes and averages, having a species richness of 4.1 in an area of 235 $m^2$ is different when comparing a species richness of 5.4 in an area of 1220 $m^2$. This difference in size may be the reason that the richness is greater outside of bridges because there is not enough space underneath the bridge to house as many. However, these results are not statistically significant, so this shows that the area underneath the bridge can house a variety of mussel species just as much as the outside, despite how much smaller the area is. Therefore, the environment underneath bridges creates a preferred habitat for a variety of species just as well as the outside since there is not a statistically higher richness outside of bridges.

*Community Structure*

Looking at community structure (Appendix III), 25 out of 32 different mussel species have a higher density found underneath a bridge than the outside. The ones which preferred outside the bridge area were mostly the ones that were collected the least, meaning if more surveys with these species were analyzed then perhaps these findings would change. As well, some species of mussel prefer to live in different substrates and areas of stream, so this may be another reason as to why those species were not found with higher densities beneath bridges. However, with 78% of the mussel species being found underneath bridges, it can be concluded that the environment in which the bridge provides is adequate for most species and seems to even be preferred when looking at density data. Looking at specific fish species that are found in the bridge area would be beneficial as well, because fish hosts are an important part to the reproductive cycle of mussels. Mussel species distribution underneath bridges may be impacted if the mussel is a generalist or specialist with their fish host and if the fish prefers the bridge environment or not.

*Potential Habitat Impacts*

Bridges have the potential to impact the stream composition and the environmental conditions found underneath them. Our findings concluded that mussels have higher densities underneath bridges, however, the factors in which explain why that occurs are yet to be fully researched. The potential factors contributing to high mussel densities underneath bridges may not only focus on what attracts host fish, but also on what may support the survivorship of the mussel communities.

Bridges have the possibility of supporting fish populations underneath them. Bridges provide shading due to their large overhead structures, which create the potential to attract fish. A study done by Meehan et al. (1987) discovered that shade is an important feature of stream habitat and influences the daytime distribution, abundance and biomass of salmon in streams. They compared artificial shade versus natural shade provided by banks, logs etc. and found that the natural shade is less reliable due to the constant changes with the sun and the much smaller shade coverage area. Therefore, fish preferred the artificially shaded areas due to the larger area and reliability. Scour pools are also commonly found underneath bridges and are a big attraction to fish. The fish attracted to this pooled habitat can correlate to why mussel densities are higher underneath bridges, but only if the correct type of habitat for mussels is found nearby (Charters et al. 2001).

Mussels are found in the same general locations of a stream that fish hosts are found in. However, there are other factors in which play into affect on where a mussel may land in the riverbed. The potential for bridges to change the hydrolic flow of the water can be one impact as to how freshwater mussels are brought to bridge sites. The water velocity can increase, which may have an effect on the distribution of mussels when the dispersing juveniles are drifting in the water. These velocity changes may also play into an effect on the fish hosts and how they distribute the mussels. The location where the juvenile mussel rests on the riverbed also depends on the velocity of the mussel itself, which would rely on the fishes swimming speed.

The type of sediment present underneath a bridge can also provide a reason in supporting mussel communities. One factor that has the possibility of impacting sediment composition entails looking at what is placed in the stream for bridge structure and stability. Rip rap is often placed underneath bridges, which has the potential to impact the environment and cause deposition in the area that can support the mussel communities. In conclusion, it would be beneficial to research these specific habitats underneath and outside of bridges in order to determine what is attracting mussels to bridge sites.

Our discovery that freshwater mussels have higher densities underneath bridges and can support a diverse community of mussels provides insight for mussel surveyors. These findings can perhaps influence any possible changes that can be implemented into survey protocols to help with mussel survivorship and with the potential to save money on conducting surveys. This research and future research at bridge sites is important towards improving mussel communities by determining how human impacts affect the adaption and survival of freshwater mussels in their changing environments.

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**Appendix I**

Table 3. Data regarding the unique identification number in correlation to its report name.

| UID | Project Name |
|---|---|
| 1 | UNIONID MUSSEL SURVEY IN BRADFORD CREEK, MADISON COUNTY, OHIO |
| 2 | Mussel survey and relocation madison lake/deer creek in madison county |
| 3 | A Report on the results of a Phase 1 mussel survey of the great miami river at the Us route 33 bridge in logan county, ohio |
| 4 | Unionid mussel survey in beaver creak, williams county, ohio |
| 5 | A report on the results of a mussel survey and relocation for AUG-66-18.19 |
| 6 | A report on the results of a mussel survey and relocation on the Middle Branch Portage River |
| 7 | A report on the results of a mussel survey and relocation on Owl Creek at the CR 25 |
| 8 | Group 1 Unionid Mussel Survey TRU-534-18.84 PID 90188 Grand River |
| 9 | A report on the results of a mussel survey and relocation on Cedar Creek at the Latcha Road |
| 10 | Blanchard river mussel survey and relocation report |
| 11 | A report on the results of a mussel survey and relocation on Silver Creek at the State Route 15 Bridge at WIL-15-00.11, Williams County, Ohio |
| 12 | A report on the results of a mussel survey and relocation on Beaver Creek at the US Route 20A |
| 13 | A report on the results of a mussel survey and relocation on Clear Fork Creek at the State Route 576 Bridge at WIL-576-20.11, Williams County, Ohio |
| 14 | A report on the results of a mussel survey and relocation on South Turkeyfoot Creek at the State Route 109 Bridge at HEN-109-8.78, Henry County, Ohio |
| 15 | GROUP 1 UNIONID MUSSEL SURVEY |
| 16 | A report on the results of a mussel survey and relocation on Beaver Creek at the County Road 20/202 Bridge in Williams County, Ohio |
| 17 | LORAMIE CREEK MUSSEL SURVEY AND RELOCATION REPORT |
| 18 | Grou p1 Unionid Mussel Survey FRA-33-24.26 |
| 19 | FRESHWATER MUSSEL SURVEY REPORT Bokes Creek Phelps Road Bridge Replacement |
| 20 | A report on the results of a mussel survey and relocation on Powell Creek at the County Road 17 |
| 21 | Ninemile Creek Mussel Survey and Relocation Report |
| 22 | Black Fork Mohican River Mussel Survey and Relocation Report |
| 23 | MUDDY FORK MOHICAN RIVER MUSSEL SURVEY AND RELOCATION REPORT |
| 24 | Grand River Phase1/Phase2 Mussel Survey Report |
| 25 | Freshwater mussel survey report rock fork MAR-23-16.76 |
| 26 | Mussel Survey and Relocation Holes Creek |
| 27 | Freshwater Mussel Survey Report SEN-19-14.34 (PID 102933) |
| 28 | Mussel Survey and Relocation Teens Run Bridge Replacement Project |
| 29 | Group 1 Unionid Mussel Survey LUC-75-1.10 PID 93594 Swan Creek |
| 30 | RIC-TR152-0.20 (PID 98716) mussel survey and relocation clear fork mohican river |
| 31 | Group 1 Unionid Mussel Survey WIL-6-20.46 Bridge Replacement |

| | |
|---|---|
| 32 | Group 1 Unionid Mussel Survey WIL-6-21.73 Bridge Replacement |
| 33 | Middle Branch Portage River Mussel Survey and Relocation Project |
| 34 | Freshwater Mussel Survey Report VAN-118-6.02 (PID 108928) |
| 35 | RUSH CREEK SURVEY AND RELOCATION REPORT UNI-CR340-2.46 Bridge Replacement (PID 99912) Washington Township, Union County, Ohio |
| 36 | Freshwater Mussel Survey Report JAC-29-8.73 (PID 98668) |
| 37 | PLUM CREEK SURVEY AND RELOCATION REPORT PUT-115-09.89 (PID 100733) |
| 38 | Freshwater Mussel Salvage and Relocation for WOO-LONG Judson Bridge (PID 98749) |
| 39 | MUSSEL SURVEY AND RELOCATION – LOR-TR72-2.91 (PID 98720) |
| 40 | GROUP 2 UNIONID MUSSEL SALVAGE AND RELOCATION LOG-33-6.41l, pid 99861 Great Miami River |
| 41 | A report on a mussel survey and relocation on Pike Run at ALL CR 88 262.pdf |
| 42 | A report on the results of a mussel survey of the Grand River at IR 90.pdf |
| 43 | A report on a mussel survey and relocation on Wrestle Creek at ALL CR 166.pdf |
| 44 | MAD-TR24-2.75 PID 16707 Mussel survey.pdf |
| 45 | ODOT Stillwater Final_all.pdf |

**Appendix II**

Table 4. Includes the date a survey was conducted, survey coordinates, stream name and stream group (1-4). Coordinates are provided in decimal degrees.

| UID | Survey Date | Latitude | Longitude | Stream Name | Stream Group |
|---|---|---|---|---|---|
| 1 | 5/5/15 | 39.8209 | -83.3868 | Bradford Creek | 1 |
| 2 | 6/1/15 | 39.88641 | -83.37674 | Deer Creek | 1 |
| 3 | 6/1/15 | 40.46533 | -83.87855 | Great Miami River | 2 |
| 4 | 7/1/15 | 41.55661 | -84.51695 | Beaver Creek | 1 |
| 5 | 8/31/15 | 40.6262 | -84.34554 | Sixmile Creek | 1 |
| 6 | 5/23/16 | 41.27891 | -83.70914 | Middle Branch Portage River | 1 |
| 7 | 5/27/16 | 41.46552 | -84.34069 | Owl Creek | 1 |
| 8 | 6/18/16 | 41.38706 | -80.95478 | Grand River | 1 |
| 9 | 6/27/16 | 41.54358 | -83.52416 | Cedar Creek | 1 |
| 10 | 10/7/16 | 41.05219 | -83.67164 | Blanchard River | 1 |
| 11 | 5/11/17 | 41.7007 | -84.5534 | Silver Creek | 1 |
| 12 | 5/13/17 | 41.5866 | -84.4813 | Beaver Creek | 1 |
| 13 | 5/23/17 | 41.6953 | -84.6311 | Clear Fork Creek | 1 |
| 14 | 5/24/17 | 41.2944 | -84.0365 | South Turkeyfoot Creek | 1 |
| 15 | 6/13/17 | 39.93743 | -83.41375 | Deer Creek | 1 |
| 16 | 8/1/17 | 41.4591 | -84.4383 | Beaver Creek | 1 |
| 17 | 8/11/17 | 40.29326 | -84.37097 | Loramie Creek | 1 |
| 18 | 8/24/17 | 39.89733 | -82.89474 | Big Walnut Creek | 1 |
| 19 | 9/6/17 | 40.423 | -83.4734 | Bokes Creek | 1 |
| 20 | 9/11/17 | 41.23868 | -84.36512 | Powell Creek | 1 |
| 21 | 9/11/17 | 40.29326 | -84.37097 | Ninemile Creek | 1 |
| 22 | 9/15/17 | 40.63578 | -82.23887 | Black Fork Mohican River | 1 |
| 23 | 9/20/17 | 40.78438 | -82.10772 | Muddy Fork | 1 |
| 24 | 10/26/17 | 41.53472 | -80.9011 | Grand River | 2 |
| 25 | 10/27/17 | 40.6851 | -83.1362 | Little Scioto River | 1 |
| 26 | 5/30/18 | 39.63404 | -84.18771 | Holes Creek | 1 |
| 27 | 6/21/18 | 41.20088 | -83.01499 | Westerhouse Ditch | 1 |
| 28 | 6/28/18 | 38.68627 | -82.19241 | Teens Run | 4 |
| 29 | 7/20/18 | 41.64274 | -83.5489 | Swan Creek | 1 |
| 30 | 8/1/18 | 40.72558 | -82.65406 | Clear Fork Mohican River | 1 |
| 31 | 9/11/18 | 41.4419 | -84.41465 | Tiffin River | 1 |
| 32 | 9/13/18 | 41.442 | -84.39023 | Brush Creek | 1 |
| 33 | 9/18/18 | 41.26942 | -83.71798 | Middle Branch Portage River | 1 |
| 34 | 9/19/18 | 40.81309 | -84.61527 | Town Creek | 1 |

| | | | | | |
|---|---|---|---|---|---|
| 35 | 9/26/18 | 40.48175 | -83.43362 | Rush Creek | 1 |
| 36 | 10/4/18 | 39.19601 | -82.67922 | Pigeon Creek | 1 |
| 37 | 7/10/19 | 40.9869 | -84.19688 | Plum Creek | 1 |
| 38 | 7/28/19 | 41.40093 | -83.84332 | Beaver Creek | 1 |
| 39 | 8/1/19 | 41.2236 | -82.20113 | West Branch Black River | 1 |
| 40 | 8/16/19 | 40.46533 | -83.87855 | Great Miami River | 2 |
| 41 | 5/29/14 | 40.84335 | -84.1785 | Pike Run | 1 |
| 42 | 10/3/13 | 41.73529 | -81.10426 | Grand River | 1 |
| 43 | 5/29/14 | 40.645270 | -84.041720 | Wrestle Creek | 1 |
| 44 | 8/18/14 | 40.0732 | -83.4025 | Little Darby Creek | 2 |
| 45 | 7/16/14 | 39.8615 | -84.2693 | Stillwater River | 1 |

**Appendix III**

Table 5. The amount of different species found in all sites combined. The number of surveys in which a species appears in is first stated. Total number of specific species found under or outside of bridge is stated, along with the density (mussels/meter$^2$) in that area. Data is also sorted from mussels species with higher densities underneath the bridge and mussel species with higher densities outside of the bridge area.

| Genus | Species | # of Surveys | Total Mussels | Mussels Under | Density Under | Mussels Outside | Density Outside |
|---|---|---|---|---|---|---|---|
| **Higher Density Under Bridge** | | | | | | | |
| Pyganodon | grandis | 36 | 1925 | 617 | 0.1305 | 1308 | 0.0453 |
| Amblema | plicata | 10 | 1228 | 524 | 0.3002 | 704 | 0.1678 |
| Lampsilis | siliquoidea | 30 | 974 | 267 | 0.1065 | 707 | 0.0618 |
| Fusconaia | flava | 16 | 662 | 139 | 0.1037 | 523 | 0.0634 |
| Lasmigona | complanata | 20 | 636 | 128 | 0.0574 | 508 | 0.0303 |
| Quadrula | quadrula | 14 | 428 | 118 | 0.0340 | 310 | 0.0174 |
| Leptodea | fragilis | 10 | 243 | 76 | 0.0303 | 167 | 0.0182 |
| Truncilla | truncata | 4 | 223 | 61 | 0.0162 | 162 | 0.0137 |
| Anodontioides | ferussacianus | 13 | 176 | 48 | 0.0454 | 128 | 0.0359 |
| Eurynia | dilatata | 4 | 159 | 19 | 0.0347 | 140 | 0.0188 |
| Potamilus | alatus | 11 | 121 | 35 | 0.0210 | 86 | 0.0099 |
| Toxolasma | parvum | 5 | 120 | 68 | 0.3372 | 52 | 0.0370 |
| Actinonaias | ligamentina | 1 | 117 | 50 | 0.3846 | 67 | 0.0427 |
| Cyclonaias | pustulosa | 6 | 70 | 27 | 0.0158 | 43 | 0.0058 |
| Utterbackia | imbecillis | 10 | 58 | 22 | 0.0103 | 36 | 0.0048 |
| Lasmigona | costata | 11 | 52 | 19 | 0.0085 | 33 | 0.0020 |
| Villosa | iris | 4 | 29 | 4 | 0.0074 | 25 | 0.0066 |
| Pleuroblema | clava | 1 | 29 | 2 | 0.0133 | 27 | 0.0086 |
| Lampsilis | cardium | 8 | 24 | 10 | 0.0066 | 14 | 0.0019 |
| Alasmidonta | marginata | 4 | 19 | 10 | 0.0042 | 9 | 0.0036 |
| Lasmigona | compressa | 6 | 12 | 3 | 0.0064 | 9 | 0.0020 |
| Ligumia | recta | 1 | 9 | 1 | 0.0077 | 8 | 0.0051 |
| Alasmidonta | viridis | 4 | 6 | 1 | 0.0089 | 5 | 0.0040 |
| Lampsilis | fasciola | 2 | 6 | 3 | 0.0033 | 3 | 0.0005 |
| Utterbackiana | suborbiculata | 1 | 2 | 2 | 0.0111 | 0 | 0 |
| **Higher Density Outside Bridge** | | | | | | | |
| Strophitus | undulatus | 15 | 53 | 9 | 0.0072 | 44 | 0.0090 |
| Obovaria | subrotuda | 3 | 10 | 1 | 0.0021 | 9 | 0.0033 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Obliquaria | reflexa | 1 | 9 | 2 | 0.0111 | 7 | 0.0130 |
| Ptychobranchus | fasciolaris | 2 | 7 | 1 | 0.0033 | 6 | 0.0010 |
| Quadrula | cylindrica | 1 | 3 | 0 | 0 | 3 | 0.0010 |
| Pluroblema | sintoxia | 1 | 2 | 0 | 0 | 2 | 0.0030 |
| Potamilus | ohiensis | 1 | 1 | 0 | 0 | 1 | 0.0019 |

**Appendix IV**

Table 6. Density (mussels/meter$^2$) of each species in the ADI underneath the bridge and in the ADI outside of the bridge area.

| Genus | Species | ADI Underneath Density | ADI Outside Density |
|---|---|---|---|
| Pyganodon | grandis | 0.1305 | 0.0274 |
| Amblema | plicata | 0.3002 | 0.1750 |
| Lampsilis | siliquoidea | 0.1065 | 0.0151 |
| Fusconaia | flava | 0.1037 | 0.0604 |
| Lasmigona | complanata | 0.0574 | 0.0271 |
| Quadrula | quadrula | 0.0340 | 0.0104 |
| Leptodea | fragilis | 0.0303 | 0.0055 |
| Truncilla | truncata | 0.0162 | 0.0157 |
| Anodontioides | ferussacianus | 0.0454 | 0.0090 |
| Eurynia | dilatata | 0.0347 | 0.0015 |
| Potamilus | alatus | 0.0210 | 0.0055 |
| Toxolasma | parvum | 0.3372 | 0 |
| Actinonaias | ligamentina | 0.3846 | 0 |
| Cyclonaias | pustulosa | 0.0158 | 0.0025 |
| Utterbackia | imbecillis | 0.0103 | 0.0010 |
| Lasmigona | costata | 0.0085 | 0.0007 |
| Villosa | iris | 0.0074 | 0 |
| Pleuroblema | clava | 0.0133 | 0 |
| Lampsilis | cardium | 0.0067 | 0.0008 |
| Alasmidonta | marginata | 0.0042 | 0.0008 |
| Lasmigona | compressa | 0.0064 | 0.0022 |
| Ligumia | recta | 0.0077 | 0 |
| Alasmidonta | viridis | 0.0090 | 0 |
| Lampsilis | fasciola | 0.0033 | 0 |
| Utterbackiana | suborbiculata | 0.0111 | 0 |
| Strophitus | undulatus | 0.0072 | 0.0027 |
| Obovaria | subrotuda | 0.0021 | 0.0012 |
| Obliquaria | reflexa | 0.0111 | 0 |
| Ptychobranchus | fasciolaris | 0.0033 | 0 |
| Quadrula | cylindrica | 0 | 0 |
| Pluroblema | sintoxia | 0 | 0.0056 |
| Potamilus | ohiensis | 0 | 0 |