

Habitat Suitability Modeling for the Reintroduction of Freshwater Mussels to the Cuyahoga River

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Abstract

Freshwater Mussels (Unionidae) were historically present in the Cuyahoga River but have become nearly extirpated and “functionally extinct” from the lower portion of the river over the past centuries due to human activity (Tevesz et al. 2012, Haag and Williams, 2014). Cuyahoga Valley National Park (CUVA) aims to reintroduce freshwater mussels to the Cuyahoga River with the goal of establishing 2-4 diverse and healthy mussel beds within the park boundary. The first step in this process confirmed the readiness of the Cuyahoga River through growth and survivorship studies in 2021-2022. Here, we take the next step in this process by identifying target species for reintroduction and suitable sites for mussel bed formation. Historical analysis and consultation with local mussel experts resulted in a list of target species for reintroduction and identification of the top five species for initial efforts which includes *Lampsilis siligoidea* (Fatmucket), *Lampsilis cardium* (Plain Pocketbook), *Actinonaias ligamentina* (Mucket), *Potamilis alatus* (Pink Heelsplitter), and *Quadrula quadrula* (Mapleleaf). Identification of suitable sites was done by creating a habitat suitability model for 15 river miles of the Cuyahoga River at CUVA using ArcGIS Pro. The model was informed by water depth, current velocity, and shear stress data generated by a HEC-RAS (Hydrologic Engineering Center River Analysis System) model provided by the US Army Corps of Engineers (USACE), as well as substrate data provided by a side-scan sonar survey of the river conducted by the US Fish and Wildlife Service (USFWS). Each variable was scaled according to mussel preference informed by a thorough literature review, and all the layers were synthesized into a habitat suitability model which identified the 11 best habitat patches for bed formation in the Cuyahoga River at CUVA. From these 11 patches a consultation call was organized with area experts during which additional information was incorporated (growth and survivorship, personal experience, access, etc.) and two sites (Rockside and Red Lock Meanders) including three patches were selected as the recommended locations for initial mussel reintroductions.

Introduction

Historically, the Cuyahoga River was home to a diverse and thriving community of freshwater mussels, but human activity has caused their population to significantly decline over the past centuries (Vaughn et al. 2008). The portion of the Cuyahoga River that runs through

Cuyahoga Valley National Park is almost completely barren of mussels, with only a single live *Lasmigona complanata* being found in a 2016 survey (Andrikanich, 2019).

Mussels are an extremely important part of freshwater ecosystems and provide many ecosystem services due to their ability to filter large volumes of water, and they are also great indicators of overall community health (Vaughn et al. 2008). Due to their sensitivity to pollution and habitat disturbance, freshwater mussels have become one of the most imperiled taxa in the world over the past decades (Sansom and Sassoubre, 2017). The reintroduction of freshwater mussels into the Cuyahoga River will be a benchmark in the recovery of the ecological health of the river, as well as an important step in the conservation of native freshwater mussels in North America.

Cuyahoga Valley National Park's Resource Management Division has partnered with the US Army Corps of Engineers (USACE), US Fish and Wildlife Service (USFWS), Ohio Department of Natural Resources (ODNR), Northeast Ohio Regional Sewer District (NEORSD), EDGE Engineering and Science (EDGE), Cleveland State University (CSU), Ohio State University (OSU), and the Columbus Zoo and Aquarium (CZA) in an effort to reintroduce freshwater mussels to the Cuyahoga River and re-establish diverse and robust mussel beds. The first phase of this project (Phase 1) is to establish 2-4 mussel beds within the park boundaries starting in Autumn of 2023, with Fatmuckets (*L. siliquoidea*) propagated at Genoa National Fish Hatchery as the focal species with additional species potentially reintroduced through translocation of adults. Mussel beds are aggregations of mussels from various species that form as juvenile mussels settle on the river bottom where substrate and hydrological factors are suitable for survival (Morales et al. 2006). The juvenile mussels mature, and their presence is thought to create flow refuges that make the habitat even more favorable for other mussels, and as more juvenile mussels settle down in the area, a mussel bed forms (Morales et al. 2006). The establishment of these initial mussel beds in the Cuyahoga should provide the foundation for additional species of mussels that can be introduced to the river in the future.

A list of Unionids that were historically present in the Cuyahoga was compiled (Tevesz et al. 2012) and a thorough literature review was conducted to understand biotic and abiotic characteristics of their preferred habitat. We identified the top five species that appeared most appropriate for this reintroduction project based on various factors such as tolerance of

disturbance, ease of obtainment, fish host presence, and overall habitat requirements. The information acquired in this literature review was used to inform and develop a habitat suitability model to identify the best locations for mussel bed establishment. The habitat model was created with ArcGIS Pro's ModelBuilder toolkit, using the model created by Collier et al. in 2021 to model lake sturgeon habitat in the Maumee River as a reference. The model used substrate type, water depth, current velocity, and shear stress as factors in generating Habitat Suitability Index (HSI) score across the northern portion of the Cuyahoga River. Model results were used to delineate potential sites for mussel bed establishment by identifying relatively large areas with the highest HSI scores (upper quartile). From these sites, two areas were selected as the recommended locations for the reintroduction of freshwater mussels.

Methods

Species Selection

An initial list of candidate species included all unionids historically present in the Cuyahoga River was provided by Tevesz et al. (2002). A literature review was conducted on the 25 species found in this list, and mussels were ranked according to their substrate, depth, and flow preferences; the presence of their host fish in the river; whether the mussels can be propagated in captivity; State and Federal conservation status; and their overall sensitivity to pollution and disturbance (Table 1). The list was discussed with a number of mussel experts experienced in both the natural history, current distribution, and habitat preferences as well as those who work in freshwater mussel propagation (Dr. Robert Krebs, CSU; Adam Benshoff, EDGE Consulting).

Mussel species with high sensitivity to changes in water quality (e.g., pollution, sedimentation and disturbance), such as *A. marginata* and *P. fasciolaris* (Watters et al. 2009) were removed from consideration. Species with unknown fish hosts, or fish hosts absent in the Cuyahoga River, such as *O. subrotunda* (Shepard et al. 2021), were eliminated as well. We decided to move away from specialist species with strict habitat requirements and select more generalist species that will thrive under a wider range of conditions for the initial phases of reintroduction. *Lampsilis siliquoidea* (Fatmucket), *Lampsilis cardium* (Plain Pocketbook), *Actinonaias ligamentina* (Mucket), *Potamilis alatus* (Pink Heelsplitter), and *Quadrula quadrula* (Mapleleaf) were selected as our five initial candidates for reintroduction to the Cuyahoga River.

Each species is further discussed below but these species all fit into the general profile of generalist species that are tolerant of pollution, prefer relatively slow-moving areas of riverine habitat, and are likely to cohabitate and form beds together allowing for a single habitat model to represent all five species.

The first species to be reintroduced to the Cuyahoga River will be *L. siliquoidea*, the Fatmucket -a widespread generalist species (Watters et al. 2009) that has been used extensively as a model organism in the study of Unionids (Luck, 2020; Perles et al. 2003). Early conversations with mussel experts suggested the Fatmucket would be an appropriate candidate for reintroduction and this species was selected prior to the full formal evaluation. There were a number of reasons this species was a good candidate but its presence and relative abundance in other areas of the Lake Erie watershed and relative ease of propagation made helped make a strong case for the Fatmucket. A silo study conducted by the National Park Service in the summer of 2022 also provided sufficient evidence that the Cuyahoga River is currently able to support this species (Herbruck et al. 2023). The Fatmucket is tolerant of almost any substrate and flow rate, and its fish hosts include Bass, Bluegill, and Yellow Perch, which are all present in the Cuyahoga River (Watters et al. 2009, [EPA Survey]).

Lampsilis cardium, the Plain Pocketbook, is a very large mussel species found throughout most of Ohio in still and flowing bodies of water and is tolerant of a wide range of substrate types (Watters et al. 2009). Fish hosts of this species include the Smallmouth Bass, Largemouth Bass, Bluegill, and Yellow Perch, which are all abundant in the Cuyahoga River (Watters et al. 2009, 2021 EPA survey). This species has also been described as an early colonizer that is beneficial to the establishment of diverse mussel beds over time (Personal communications, Adam Benshoff).

Species	Common Name	Fish Host Presence	Substrate typically used	Flow	Conservation Status
<i>Actinonaias ligamentina</i>	Mucket	Y	Sand, gravel, cobble	Med	
<i>Alasmidonta marginata</i>	Elktoe	Y	Sand, gravel, cobble	High	Concern (OH)
<i>Amblema plicata</i>	Threeridge	Y	Firm mud, sand, gravel	Any	
<i>Anodontoides ferussacianus</i>	Cylindrical Papershell	Y	Silt, clay, gravel, cobble	Headwaters	
<i>Cambarunio iris</i>	Rainbow Mussel	Y	Sand, gravel	Med	Concern (OH)
<i>Eurynia dilatata</i>	Spike	Y	Sand, gravel, mud	Small rivers/creeks	
<i>Fusconaia flava</i>	Wabash Pigtoe	Y	Mud, sand, gravel	Med, large rivers	
<i>Lampsilis cardium</i>	Plain Pocketbook	Y	Mud, sand, gravel, etc.	Any	
<i>Lampsilis fasciola</i>	Wavy-Ray Lampmussel	Y	Sandy mud, sand, gravel	Med to High	Concern (OH)
<i>Lampsilis siliquoidea</i>	Fatmucket	Y	Any	Any	
<i>Lasmigona complanata</i>	White Heelsplitter	Y	Mud, silt, sand	Low	
<i>Lasmigona compressa</i>	Creek Heelsplitter	Y	Sand, gravel	Low to Med	Concern (OH)
<i>Lasmigona costata</i>	Flutedshell	Y	Sand, mud, gravel	Low to Med	
<i>Leptodea fragilis</i>	Fragile Papershell	Y	Sandy mud, gravel	Any	
<i>Sagittunio nasutus</i>	Eastern Pondmussel	Y*	Sandy mud	Low	Endangered (OH)
<i>Ligumia recta</i>	Black Sandshell	Y	Sand, gravel, mud	High	Threatened (OH)
<i>Obovaria subrotunda</i>	Round Hickorynut	Y	Sand, gravel, sandy mud	Med to High	
<i>Pleurobema sintoxia</i>	Round Pigtoe	Y	Gravel, cobble, sand, silt	Med to High	Concern (OH)
<i>Potamilus alatus</i>	Pink Heelsplitter	Y	Sand, silt, mud	Low	
<i>Ptychobranchus fasciolaris</i>	Kidneyshell	Y	Sand, gravel	Med	Concern (OH)
<i>Pyganodon grandis</i>	Giant Floater	Y	Any	Low to Med	
<i>Quadrula quadrula</i>	Mapleleaf	Y	Mud, sand, gravel	Low to Med	
<i>Strophitus undulatus</i>	Creeper	Y	Mud, sand, gravel, cobble	Any	
<i>Toxolasma parvum</i>	Lilliput	Y	Muddy sand, clay	Low	
<i>Utterbackia imbecillis</i>	Paper Pondshell	Y	Mud, silt	Low	

* No natural infestations have been observed

Actinonaias ligamentina, the Mucket, is found throughout the drainage systems of the Great Lakes and was historically present in a majority of the large rivers in Ohio but was likely extirpated in most of the state in the early 20th century (Watters et al. 2009). There are two known subspecies of this mussel: *ligamentina* and *carinata*, it is unclear which will be chosen for reintroduction. This species is commonly found in moving water, in firm substrates such as gravel, cobble, and sand (Watters et al. 2009).

Potamilus alatus, the Pink Heelsplitter, is a unique and aesthetically pleasing mussel found in the Mississippi River and Great Lakes drainage systems (Watters et al. 2009). This species is normally found in slower currents or still water and prefers softer substrate such as mud and silty sand (Watters et al. 2009). The only known fish host for this species is the Freshwater Drum (Watters et al. 2009), this species is present in the Cuyahoga but was historically restricted to below the Canal Diversion Dam and has likely moved up stream since its removal in 2020 (based on Ohio EPA fish surveys 1974-2018).

Quadrula quadrula, the Mapleleaf, is a species of mussel with a characteristic thick, bumpy shell. The range of this species stretches across the entire Mississippi River system, and it is found in the Great Lakes as well (Watters et al. 2009). The Mapleleaf is commonly found in larger bodies of water with a decent current and is associated with many types of substrates such as mud, sand, and gravel (Watters et al. 2009). The fish hosts of this species are the Channel and Flathead Catfish, which are both present in the Cuyahoga River (Watters et al. 2009, Ohio EPA Fish Survey, 2018). The Mapleleaf was one of the first mussel species to recolonize the upper Illinois River, which had previously been extirpated of all mussels, with no human intervention (Sietman et al. 2001).

Study Area

Only the northern half of the Cuyahoga River at CUVA was evaluated for the initial reintroduction effort (between river miles 13 and 29) [Figure 1], this is due to two factors: data availability and results of earlier 2021-22 growth and survivorship studies. The HEC-RAS model that provided the depth and flow data to inform the habitat model only covers the portion of the

river flowing through the northern portion of the National Park, from Peninsula to Rockside Road.

An adult survivorship study was conducted in the summer of 2021 using Mucklets collected from the Grand River, placed in enclosures in the Cuyahoga River. This study found a 96% survival rate with no observable variation across sites (Trimbath R.J., 2022). As a follow up, a juvenile growth and survivorship study was conducted on the Cuyahoga River within the National Park boundary in the summer of 2022 (Herbruck et al. 2023). In this study, 26 silos, each containing 10 juvenile Fatmucklets, were deployed at various sites along the river. Five control silos were placed in the Grand River, a nearby river that currently possesses a healthy mussel community. The silos were placed in the river from June 8th to September 21st and were removed once for a midpoint check on August 10th. The mussels were weighed and measured to assess their survival and growth in each river.

This study found that 46% of the Fatmucklets deployed in the Cuyahoga River silos survived by the final check in September, while 50% of the mussels at the Grand River control site survived. These survival rates are fairly typical of cage/silo studies performed in healthy rivers (Haag et al. 2019), and a few of the silos in the Cuyahoga became completely packed with sediment, killing all mussels, and lowering the overall survival in the river. Additionally, silos located further downstream (north) saw higher levels of growth and survival than those placed in the more upstream sites in the Cuyahoga, suggesting that the sites in the northern part of the park would be most suitable for the initial reintroduction effort.

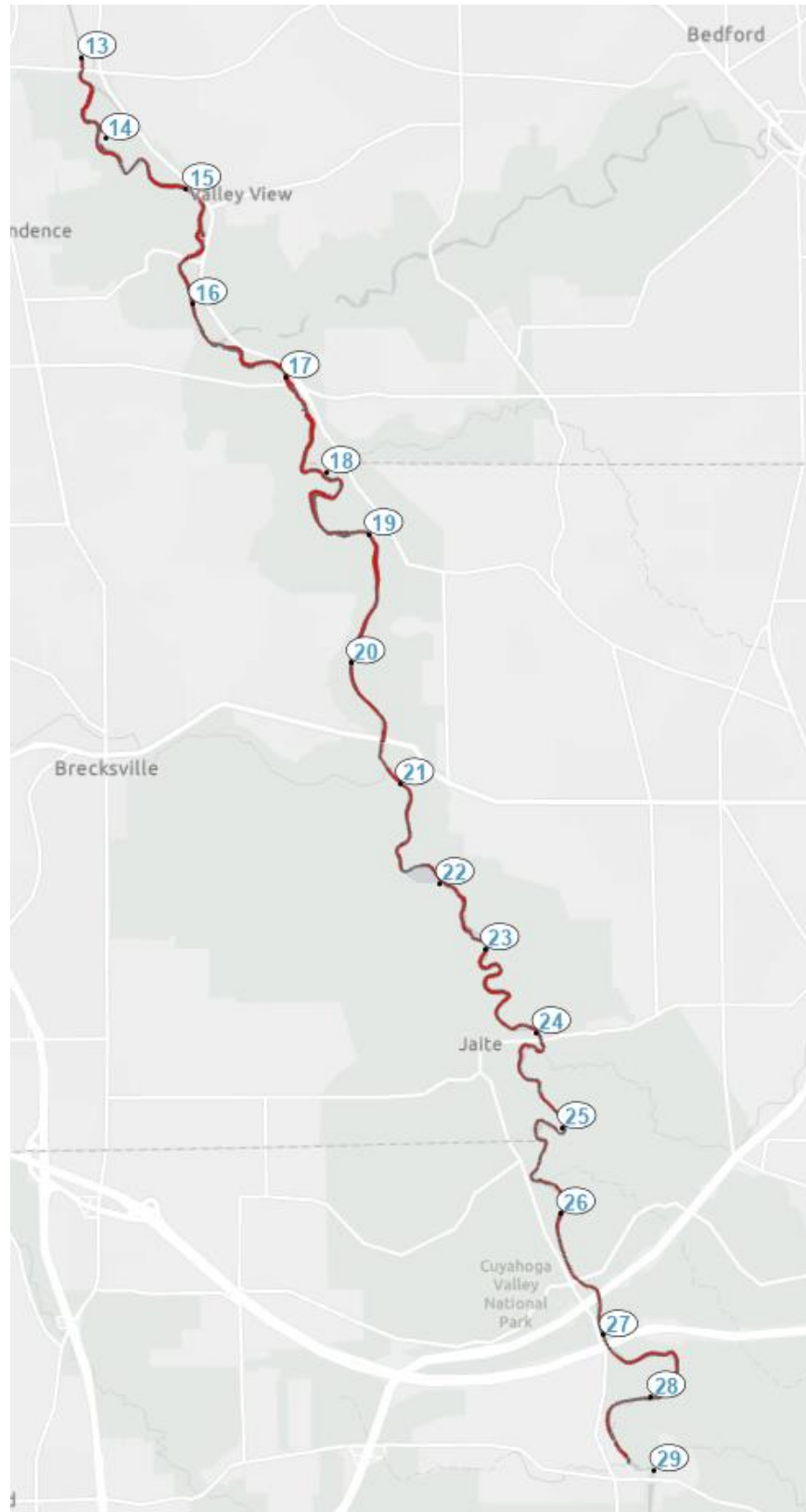


Figure 1: Area modeled shown in red, river mile markers are shown in blue

Modeling

The aim of this project was to identify ideal locations to establish mussel beds suitable for the five selected species. The modeling effort conducted by Collier et al. in 2022 to model lake sturgeon habitat in the Maumee River was used as a basis for the creation of this mussel habitat model. This study considered water depth and velocity as well as river substrates as important factors in determining good sturgeon habitat; these factors are also paramount to mussel survival and bed formation, so we used them as the primary variables in our mussel habitat model as well. Additionally, USFWS is in the process of conducting lake Sturgeon habitat modeling on the Cuyahoga River and has compiled the same data sets/types on the Cuyahoga as those used on the Maumee. The availability of this data made it possible to conduct the habitat modeling for freshwater mussels in the Cuyahoga River.

Water depth (Figure 2), current velocity (Figure 3), and shear stress [Figure 4] models were generated by USACE's Hydrologic Engineering Center's River Analysis System, or HEC-RAS, software. The 2-Dimensional HEC-RAS model was performed for the northern portion of the Cuyahoga River, simulating low-flow (will be exceeded 80% of the time), bank-full flow (the absolute maximum water level the river can reach without overflowing), 1-year annual chance exceedance (high flow that has a 99.99% chance of occurring in any given year), and 2-year annual chance exceedance (high flow that has a 50% chance of occurring in any given year) conditions. The units for depth and velocity were feet, and feet per second, respectively. Raster files containing depth and velocity data for the selected flow conditions were exported from the HEC-RAS modeling software and were imported into ArcGIS Pro (version 3.03) to be incorporated into the mussel habitat model.

Substrate data (Figure 5) was generated from a sonar survey performed by the US Fish and Wildlife Service. Between May and July of 2022, Humminbird Helix and 1198 side-scan sonar units were used to collect data for the stretch of the Cuyahoga River from the confluence with the Little Cuyahoga, downstream to Lake Erie. The data was then cleaned and processed in ReefMaster 2.0 and exported as .kml files. The imagery generated from the sonar unit was visually classified into areas of different substrate types (e.g., sand, gravel, cobble) by the Fish and Wildlife Service as well. The resulting substrate classification polygons were compared with a ground truth survey conducted in 2021 to ensure accuracy.

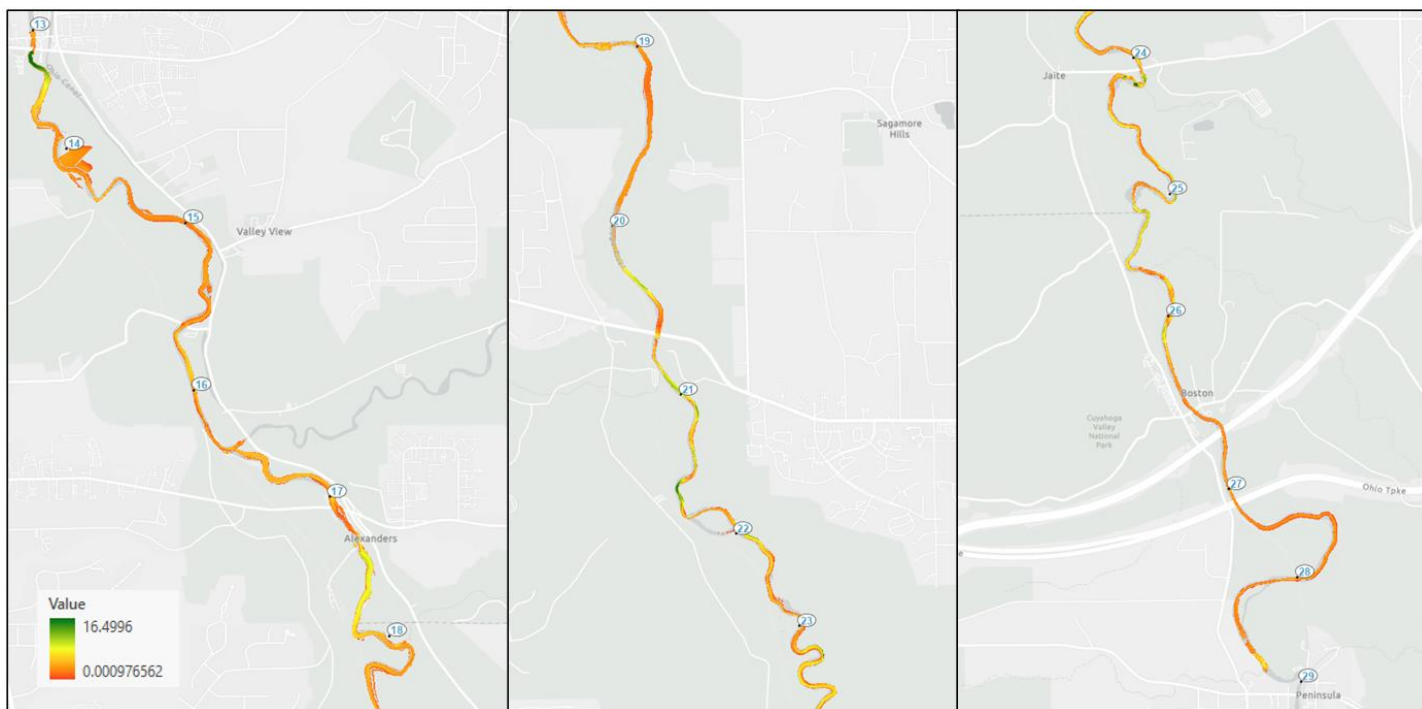


Figure 2: Raw depth data for the modeled portion of the Cuyahoga River under low-flow conditions. Units: feet.

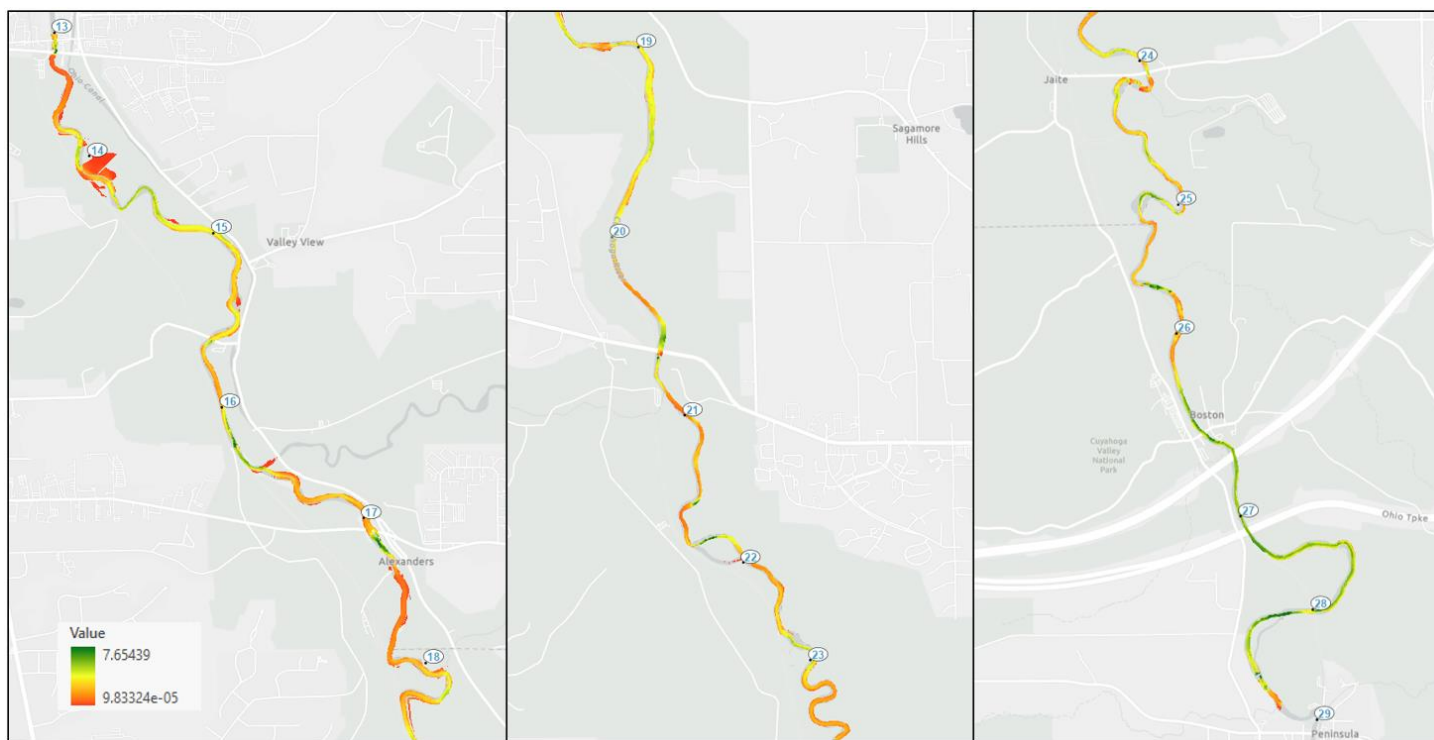


Figure 3: Raw velocity data for the modeled portion of the Cuyahoga River under low-flow conditions. Units: feet per second.

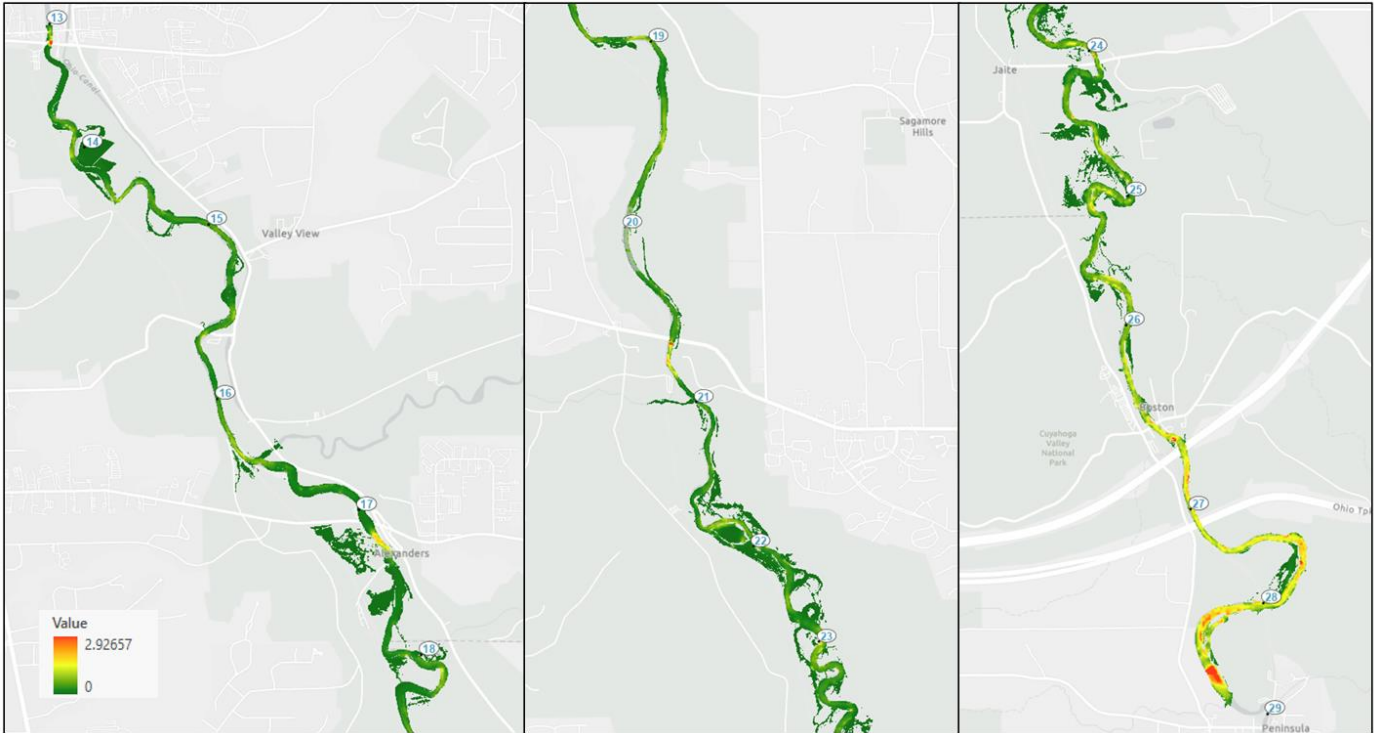


Figure 4: Raw shear stress data for the modeled portion of the Cuyahoga Rive under bank-full conditions. Units: pounds per square foot.

Note: This layer shows some areas that overflow the boundary of the Cuyahoga River. This is because we chose to use bank-full conditions to represent shear stress in the model. These overflowing regions are clipped out of the final model.

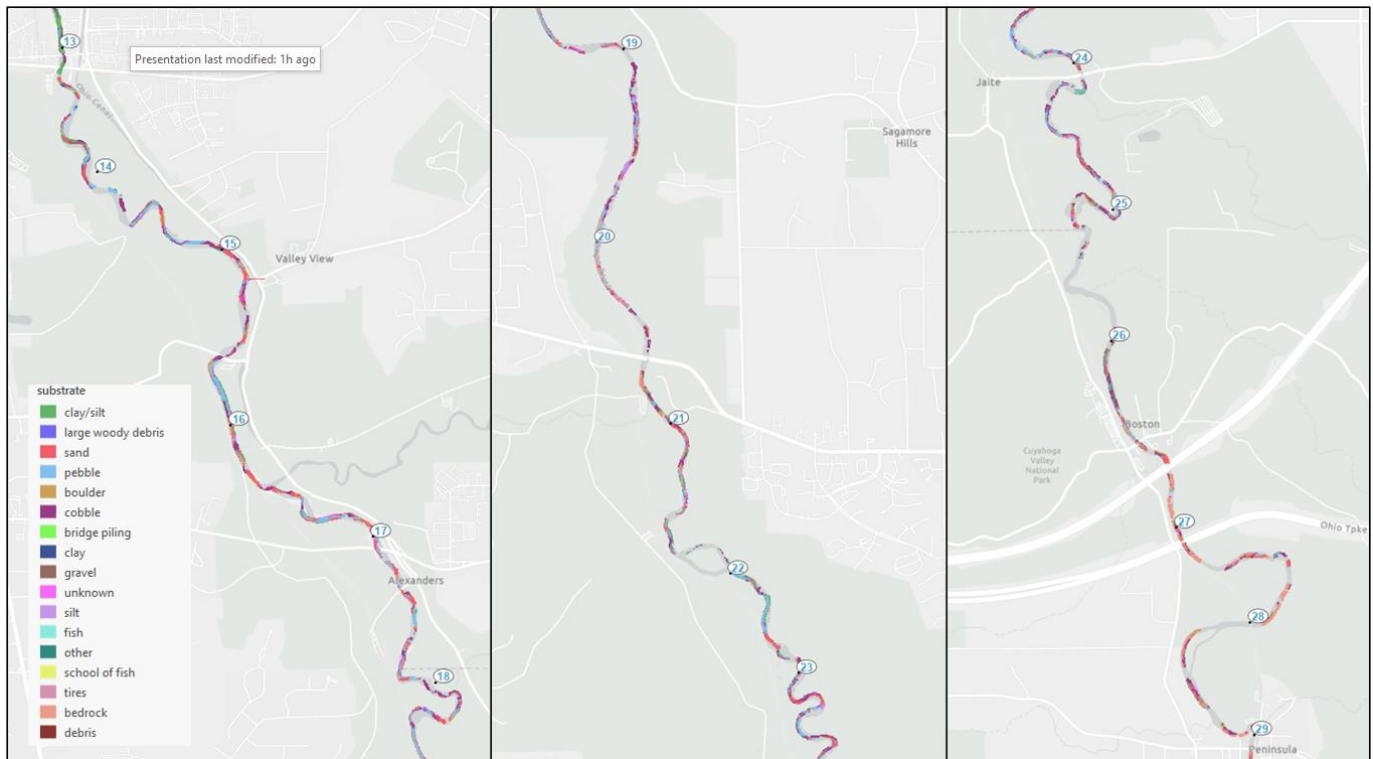


Figure 5: Raw substrate data for the modeled portion of the Cuyahoga River.

The depth and velocity raster files were reclassified in ArcGIS Pro, each tile of the raster file was given a score from 1-10 based on the suitability of the depth or current at the locality, with 1 representing the lowest preference, and 10 representing the highest. The depth raster was rescaled using the Gaussian distribution function, giving greater preference scores to areas with depth between 0.5 and 3 feet, with preference decreasing as values strayed outside of the range. The velocity raster was reclassified by the logistic decay function, giving higher preference scores to areas with the lowest current velocity.

Shear stress has been shown to be another important variable to consider when assessing potential mussel habitat (Randklev et al. 2019; Key et al. 2021). Shear stress is a measure of the force exerted on substrate particles by the flow of the river, the data provided was in units of pounds per square foot. High levels of shear stress result in sediment being washed away, which is detrimental to mussel bed formation (Holland Bartels, 1990). Shear stress levels are typically positively correlated with higher water levels, so the shear stress levels generated by the HEC-RAS model under the highest flow conditions were used to inform

Substrate types were given scores based on the preferred substrates of slow-water mussel species. These species tend to prefer softer substrates that are easy to embed into, but they are also tolerant of harder substrates such as gravel and pebbles. Rocky substrates with extremely large grain sizes are the least conducive to mussel bed formation, so they were given the lowest scores. The scores assigned to each substrate type were sand: 10, silt: 9, clay/silt: 8, clay: 7, gravel: 6, pebble: 5, cobble: 3, boulder: 2, woody debris: 2, and bedrock: 1.

After the individual data layers were created and weighted, they were combined into a single suitability layer using the weighted sum tool in ArcGIS Pro. The resulting raster layer showed areas of the river that were most suitable for freshwater mussel bed formation based on the three input datasets. The weighted sum process generated a HSI score for each cell of the raster. The mean and standard deviation of this dataset were calculated, and all cells with a score that was one standard deviation above the mean were selected as the most suitable habitat.

Delineation of Habitat Patches and Site Selection

Cells with HSI scores in the upper quartile of the range were categorically defined as the “best” habitat. These cells were isolated and displayed on the map in a new layer, allowing for

easier analysis of the final results of the model. Each subsequently lower quartile was categorially labeled as good, moderate, or poor habitat respectively (Figure 6.). The largest continuous patches of cells representing the best habitat were manually delineated into polygons, each of which was then considered as a potential location for reintroduction. Several factors were taken into account when selecting the final sites for reintroduction, including ease of access, and expected levels of foot and boating traffic.

Results

Of the species historically found in this portion of the Cuyahoga River, we selected *Lampsilis siliquoidea* (Fatmucket), *Lampsilis cardium* (Plain Pocketbook), *Actinonaias ligamentina* (Mucket), *Potamilis alatus* (Pink Heelsplitter), and *Quadrula quadrula* (Mapleleaf) as ideal candidates for the initial introduction effort. The first species to be introduced will be the Fatmucket, because there is already substantial evidence that the Cuyahoga River is able to support this species (Herbruck et al. 2023). In autumn of 2023, juvenile Fatmuckets reared at the Genoa National Fish Hatchery (USFWS) will be released into the Cuyahoga, we recommend the release take place at the sites identified through this habitat modeling exercise.

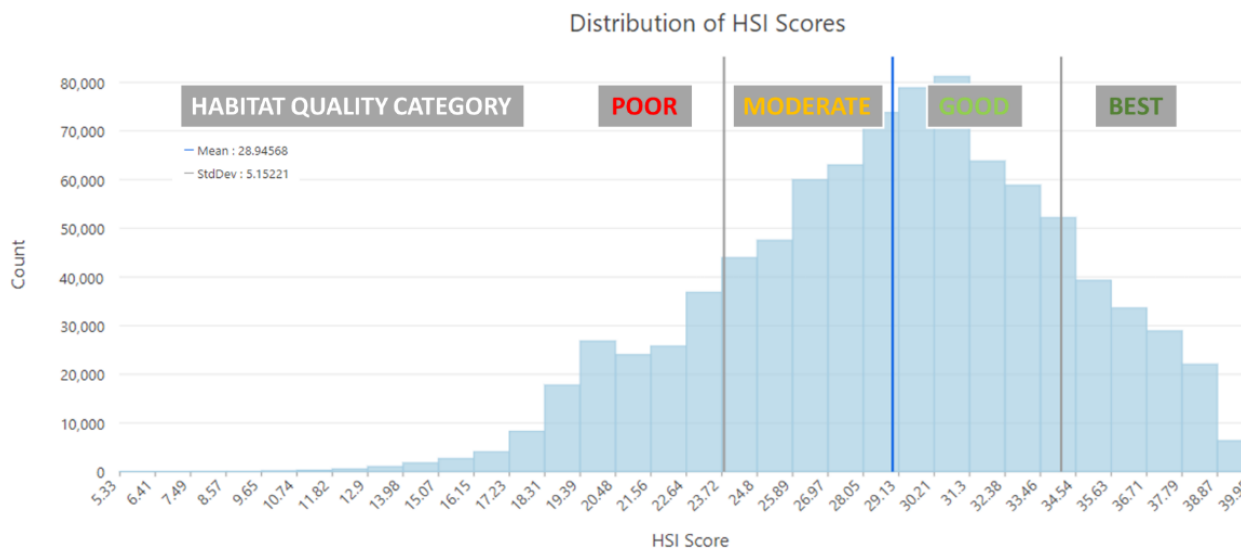


Figure 6: Distribution of HSI scores

Approximately 15.79 river miles of the Cuyahoga River were modeled in this study, covering a total area of approximately 213.64 acres. The raster cells with HSI scores in the upper quartile (one standard deviation above the mean) of the overall range of scores (about 40.86 acres total) were selected as the best habitat in the study reach. The largest patches of the most suitable habitat were identified and selected for consideration to be initial mussel launch sites. This included 11 patches that ranged in size from 3.94 acres to 15.39 acres, with a mean area of 7.53 acres.

Patch ID	River Mile	Site Name	Area (Acres)	Length (feet)
1	13.5	Rockside	4.8	1215.9
2	14	Rockside	5.3	1035.5
3	15.25	Valley View	3.9	1196.2
4	16	CEC	6.6	1803.7
5	17	Pleasant Valley	14.4	3199.1
6	18	Fitzwater	8.6	2033.6
7	18.25	Fitzwater	9.5	1750.3
8	20.25	Pinery Narrows	3.4	890.9
9	22.25	CMA	9.6	2306.9
10	23.5	Jaite Meanders	15.4	4545.7
11	26	Boston North	8.5	2583.7

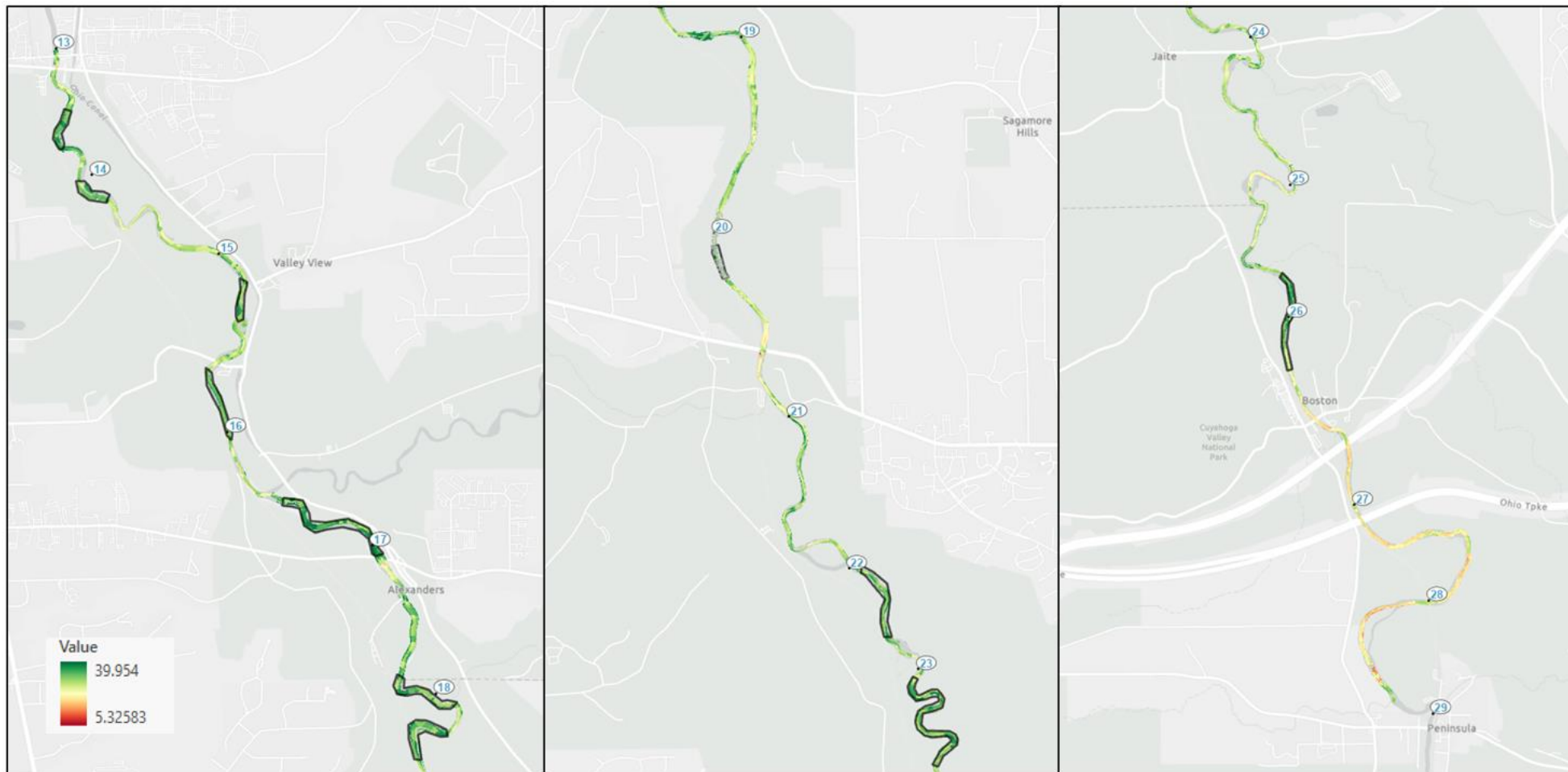


Figure 7: Model results, represented by a unitless HSI score. Potential reintroduction sites are outlined in black

Discussion

Habitat modeling resulted in the discovery of extensive areas of the Cuyahoga River in CUVA that are suitable for freshwater mussel reintroduction. A total of 11 patches were identified as potential locations for the initial reintroduction of freshwater mussels and the establishment of mussel beds. From these sites we have identified 2 specific locations recommended for the initial reintroduction. These sites were identified as high-quality habitat suitable for the top five candidate species: *Lampsilis siliquoidea* (Fatmucket), *Lampsilis cardium* (Plain Pocketbook), *Actinonaias ligamentina* (Mucket), *Potamilis alatus* (Pink Heelsplitter), and *Quadrula quadrula* (Mapleleaf). However, future reintroductions should not be limited to these species rather these species may be targeted for building the foundation for more diverse mussel beds. Future efforts may target additional sites as ongoing monitoring informs adaptive management of freshwater mussel restoration at Cuyahoga Valley National Park.

We chose two of these sites to recommend for the initial deployment of Fatmuckets in 2023. The first site is just south of Rockside Road, near the northernmost portion of the park. This area of the river was also a site for the mussel survival study in 2022 (Herbruck et al. 2023) and had the highest growth and rate of survival across all sites in the study, including the control area in the Grand River. Additionally, this portion of the river should be easily accessible for mussel deployment and monitoring, while not having a high level of traffic from hikers and kayakers. There are two patches of desirable habitat in this area that are very close to each other, these sites have very similar hydrological conditions and either one or both can be used for mussel deployment.

The second site chosen was a long stretch of meanders near Red Lock Trailhead, just north of the National Park's headquarters at the former site of the Jaite paper mill. This was the largest patch of suitable habitat that was identified, as wide meanders slow down the river's current and create refuges of soft substrate that are beneficial for mussel bed formation (Perles et al. 2003). The area should be fairly easy to access through trails and service roads and should have little to no foot traffic from park visitors. The young mussels should be placed in the sandy patches on the insides of the bends, as Fatmuckets prefer to be on the inner side of meanders (Krebs, personal contact).

The Fatmuckets (*L. siliquidea*) that will be used for the initial reintroduction effort will be propagated at the National Fish Hatchery in Genoa, Wisconsin (USFWS). Mussels sourced from a local population (Fred Fuller Park in Kent, Ohio) are being used to produce the stock of juvenile mussels, which are currently being reared in tanks at the hatchery. The mussels will arrive at the park in the early autumn of 2023 when they are approximately 1 year old, a subset will be grown out to 2 years old prior to release. Mussels will be tagged and introduced into the Cuyahoga River shortly thereafter.

When the mussels are deployed, select individuals will be fitted with PIT tags secured to their outer shells, this will allow the population's health and survivability to be monitored in the future through manual surveys. The US EPA may also provide monitoring support through the use of eDNA analysis to determine the presence/absence as well as abundance of different mussel species in the river (Sansom and Sassoubre, 2017).

We are also pursuing opportunities to introduce *L. cardium*, *A. ligamentina*, *P. alatus*, and *Q. quadrula* to the Cuyahoga in subsequent years. The introduction of additional species will open many avenues for research projects in the park. Different combinations of species can be placed in the river at varying population densities to observe how these factors influence bed formation over time. John Navarro the lead mussel biologist with Ohio Department of Natural Resources has suggested these identified habitat patches may be used as sites used for translocation of adult mussels impacted by construction projects in other watersheds. Navarro tentatively approved translocation of adult mussels to help build mussel beds at CUVA. Future conversations will be necessary to develop a plan for translocation of adult mussels.

The analysis performed in this report will be conducted on the 44 river miles between the Gorge Dam in Akron and the mouth of the Cuyahoga River in Cleveland once USACE and USFWS is able to provide data for the remaining portion of the river. The resultant models can be fine-tuned to better suit other species such as the Mucket (*A. ligamentina*), which may prefer higher water currents than the Fatmucket or other slow-water species which this initial model was designed around.

Rockside Road



Jaite Meanders

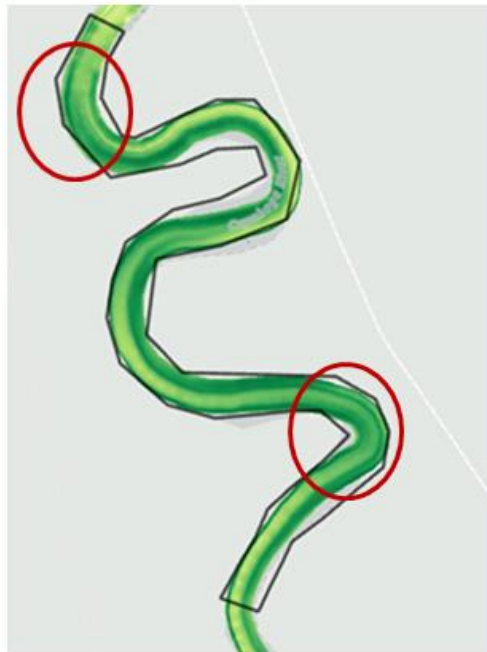
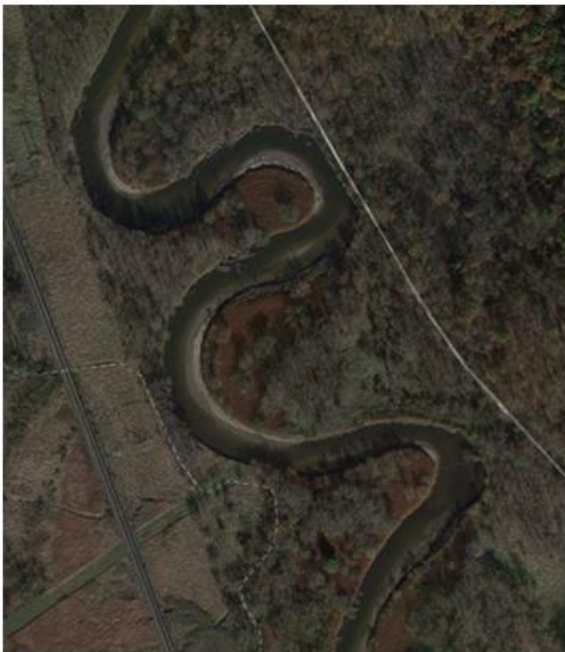


Figure 8. Zoom in showing primary sites selected for mussel reintroduction.

Areas of Concern

The removal of the Gorge Dam in Akron Ohio is scheduled for 2025. This is a large dam about 22 river miles upstream of our nearest reintroduction site. The [agency?] is planning to remove most of the contaminated sediment in the dam pool before the demolition of the dam, but there still may be a large influx of sediment as well as other significant hydrological changes to the Cuyahoga River in the National Park boundaries as a result of the dam removal. Though dam removal has been shown to benefit native mussel assemblages over several years (Barnett et al. 2021), the immediate effects of the dam removal such as sedimentation and hydrological instability may pose a threat to the mussels that have been recently introduced to the river.

Another concern for the introduced mussel population is the use of the herbicide glyphosate to control invasive vegetation in the park, as well as to control weeds in lawns and agricultural land in the vicinity of the Cuyahoga River. Studies have shown that glyphosate is acutely toxic to the glochidia and adult life stages of unionids such as *L. siliquoidea* (Bringolf et al. 2007), but this chemical is very widely available and commonly used. Additionally, the use of herbicides may be the only effective method to treat the invasive Japanese Knotweed (*Reynoutria japonica*) that has taken over the banks of the Cuyahoga River. This plant can spread vegetatively through fragments of its stem and rhizome, so mechanical treatments will be ineffective, and herbicide use may be the only effective way to control this species.

Mussel bed stability is another major concern for this undertaking. The Cuyahoga River is subject to wildly changing flow conditions throughout the year, and a flood event could greatly disturb or even completely wash out an immature mussel bed. Paired with the planned removal of the Gorge Dam and other park-sponsored river restoration projects such as re-meandering and bank stabilization that could cause drastic changes to the hydrology of the Cuyahoga River, this is a cause for concern for this restoration project. The mussel beds will have to be carefully monitored, and park personnel will need to keep in close contact with local agencies to minimize the impacts of these projects on the establishing mussel beds.

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Appendices:

All files can be found on the CUVA X drive:

GISDATA(\\inpcuvarm1)(X:) > MapProjects > Cuyahoga River Mussel Reintroduction

Modeling Tutorial: Products > MusselModel_Tutorial.docx

Full Species Selection Table: LiteratureReview > MusselRanking.xlsx

Data Used: MusselProjectData > HydroData and SedInterp

Mussel Team Contacts: Products > MusselTeam

Guide to Files: