Citizen Science Monitoring of Freshwater Mussels (Unionidae) in the Huron River Watershed, Michigan

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science (School for Environment and Sustainability) at the University of Michigan, 2023

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Abstract

Freshwater mussels (Unionidae) are a widely diverse group that serve significant roles in aquatic ecosystems. The ecosystem roles of unionids include filtering algae and nutrients from water, providing habitat for aquatic macroinvertebrates, and providing food for predators such as muskrats and raccoons; because of their sensitivity to pollution they act as water quality indicators. However, populations of unionids are severely imperiled and their distribution and abundance have been greatly reduced, especially in Michigan where 18 of our 43 unionid species are state protected and six of which are federally protected. This decline is primarily due to threats such as river impoundment, overharvesting, the spread of exotic species, and pollution.

A collaboration was developed with the Huron River Watershed Council (HRWC) to design a citizen science monitoring program using volunteers to assess the distribution and abundance of mussels across the Huron River watershed. The program design includes survey protocols, educational materials, and state and federal recommendations and regulations for HRWC to conduct their monitoring program. Through the implementation of this project, HRWC will be able to protect native mussels by identifying where native mussels are located and where they might need support from the organization's other restoration initiatives. Involving the public in this program will spread awareness for freshwater mussels to garner more support for conservation and will improve community relationships with the river by teaching people about the river's ecology and the connections to society. This project aims to be an ecologically and socially beneficial program that will enhance the lives of humans and other animals in the Huron River Watershed.

Acknowledgements

I would like to thank my primary advisor Dr. Sara Adlerstein-Gonzalez for her support and guidance throughout this thesis, as well her continued role as a source of encouragement during my time at the University of Michigan. Additionally, thanks to Dr. Karen Alofs for being the second reader and providing suggestions for this manuscript.

I am incredibly grateful to have been able to work with Jason Frenzel, Dr. Paul Steen, and staff from HRWC through this collaboration. Special thanks to HRWC's volunteers Larry Scheer and Matthew Paper for helping me visit sites even during some cold, snowy days.

I'd like to thank Dr. Renee Mulcrone for spending time to train me on mussel surveys and for being a valuable wealth of knowledge and resources for this project. Special thanks to Joseph Rathbun as well for providing copies of mussel brochures and posters to donate to HRWC volunteers.

Warm thanks are due to Syrena Kapsa and the staff at CultureVerse for working with me to produce the set of 3D models and donating them to us at no cost. I look forward to further collaboration with them on a virtual gallery and am incredibly grateful for the opportunity to involve my two passions of science and the arts.

I am especially grateful and appreciative for the Huron River and its freshwater mussels, and I look forward to being a steward of unionid conservation as well as promoting awareness about our river ecosystems to get communities involved in conservation.

Lastly, I am most of all thankful for my family for always supporting me throughout all my academic, scientific, and artistic endeavors.

Table of Contents

List of Tables

1. Introduction

Freshwater mussels (Unionidae) are underappreciated animals that have significant roles in Michigan's aquatic ecosystems. Unionid mussels filter algae, bacteria, and nutrients from the water as their source of food and in turn are prey to predators such as muskrats, raccoons, salamanders, and fish (Mulcrone & Rathbun, 2018). Unionids' sedentary adult forms provide habitat for animals such as worms and insect larvae (Vaughn & Spooner, 2006). Unionids are water quality indicators since they accumulate contaminants due to their filter feeding behaviors making them sensitive to changes in habitat quality (Green et al., 1989; Shevchuk et al., 2021). Unionid diversity is also related to fish diversity because mussel glochidia, which are a parasitic microscopic mussel larval stage, attach to the bodies of fish hosts as they grow to become adult mussels, and each mussel species uses different fish species as hosts (Jones, 2015). Therefore, high species richness of unionids can denote high fish diversity and high habitat quality.

There are 43 species of freshwater mussels currently identified in Michigan, 18 of which are listed as state threatened or endangered pursuant to Part 365, Endangered Species Protection, of the Michigan Natural Resources and Environmental Protection Act (1994 PA 451) and six of which are federally listed and receive additional protection pursuant to the Endangered Species Act (87 Stat. 884, as amended 16 U.S.C.§ 1531 et seq.) (Legislative Service Bureau, 1994; Mulcrone & Rathbun, 2018). There are 34 species of mussels recorded in the Huron River Watershed in southeastern Michigan. Of these, 12 species are state listed and four species are federally listed, including Northern riffleshell (*Eplioblasma torulosa rangiana*), snuffbox (*Epioblasma triquetra*), rayed bean (*Villosa fabalis*), and round hickorynut (*Obovaria subrotunda*) (Badra, 2010; Mulcrone & Rathbun, 2018; U.S. Fish & Wildlife Service, 2020;

Williams, 2023) (Appendix A). With so many of Michigan's unionid species listed as threatened or endangered, monitoring and conservation efforts are necessary to protect the populations that remain and to provide any hope for recovery where they have been depleted.

1.1 Background and literature review

1.1.1 Michigan Unionidae

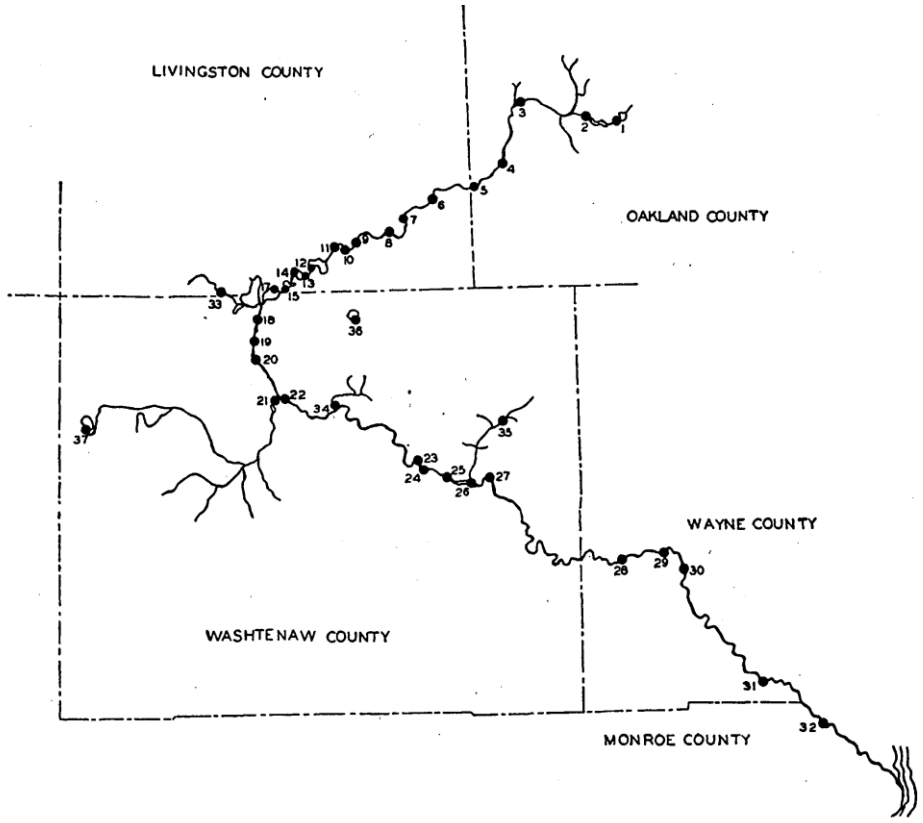
Michigan is home to 43 known species of mussels within the order Unionidae, including species found widespread throughout the state such as cylindrical papershell (*Anodontoides ferussacianus*), giant floater (*Pyganodon grandis*), creeper (*Strophitus undulatus*), plain pocketbook (*Lampsilis cardium*), fat mucket (*Lampsilis siliquoidea*), and spike (*Eurynia dilata*) (Mulcrone & Rathbun, 2018). The distribution of mussel species is related to habitat suitability that varies for each species, alongside the diminishing amount of available habitat that currently exists (Michigan Natural Features Inventory, n.d.-b). In particular, substrate preferences differ between species and some have wider ranges of suitable substrate characteristics than others. For instance, the pink heelsplitter (*Potamilus alatus*) is found in rivers and lakes with mud, gravel, or sand substrates, while other species with narrower niches, such as the federally endangered white catspaw (*Epioblasma perobliqua*), prefer more stable substrates like gravel (Michigan Natural Features Inventory, n.d.-a; Michigan Natural Features Inventory, n.d.-c; Pandolfo et al., 2016). Hydrological variability and surface geology characteristics can also shape habitat suitability for freshwater mussels. For example, Wabash pigtoe (*Fuscionaia flava*) and threeridge (*Amblema plicata*) prefer more active river conditions with more frequent flooding events, compared to spike (*Eurynia dilatata*) and fluted-shell (*Lasmigona costata*) that are more commonly found in stable river environments (Maio & Corkum, 1994).

Mussel species distribution is also dependent on the distribution of host fish species. Some unionids species are host generalists and can use multiple fish species as hosts. For example, the black sandshell (*Ligumia recta*) has over 15 species listed as hosts (Mulcrone, 2006b). Other mussels are host specialists with only a few host species, such as the fluted-shell (*Lasmigona costata*) that is known to include banded darter, longnose dace, and northern hogsucker as hosts (Mulcrone, 2006a). Host species presence is necessary for mussels to complete their reproductive cycle and thus their presence can be a predictor of habitat suitability for mussels (Mulcrone & Rathbun, 2018). One exception is paper pondshell (*Utterbackia imbecillis*) whose glochidia can develop within the female mussel without needing an external host (Dickinson & Sietman, 2008). However, host generalist mussel species are not necessarily always more abundant than host specialists. Examples include the host specialist fluted-shell being a common species in Michigan and the host generalist black sandshell being a Michigan state threatened species. Thus, host species abundance and diversity can be a complex factor determining mussel distribution.

The Huron River watershed has 34 observed unionid species (Fig. 1), 12 of which are listed as state threatened or endangered and four of which are listed as federally threatened or endangered, including the round hickorynut (*Obovaria subrotunda*) which was recently listed as federally threatened effective April 10, 2023 (Mulcrone & Rathbun, 2018; Williams, 2023) (Appendix A). Past surveys have examined parts of southeastern Michigan rivers and lakes to assess mussel abundance and diversity. Van der Schalie's 1938 report of the Huron River has extensive comparisons of species distributions throughout the watershed (Fig. 2; Table 1). Van der Schalie (1938) observed and recorded accounts of 25 species of unionids along 37 sites in the Huron River and described their abundance across different habitat types. Peter Badra (2010)

conducted a survey of mussels in the Huron-Clinton Metroparks for the Michigan Natural Features Inventory (MNFI) and found 16 mussel species in the Huron River watershed across 21 sites, including live specimens from 12 species and dead shells from four species. Of these Metroparks surveys, the Huron Meadows was the most speciose with 14 species observed (Badra, 2010). These past surveys were used to identify potential monitoring sites for this proposed design of HRWC volunteer program.

Figure 1. The 34 unionid species that are found in the Huron River Watershed. All the starred species are state listed. The four species with red stars are federally listed, including the federally endangered Northern riffleshell (Epioblasma torulosa), the federally endangered snuffbox (E. triquetra), the federally threatened round hickorynut (Obovaria subrotunda), and the federally endangered rayed bean (Villosa fabalis).



MAP 2. Locations in the Huron River of the type stations referred to in the ecological studies.

Figure 2. Mussel survey sites in the Huron River, taken from Van der Schalie (1938).

Table 1. Mussel species of the Huron River, taken from Van der Schalie, (1938).

TABLE III

DISTRIBUTION OF NAIADES IN THE DIFFERENT HABITAT TYPES IN THE HURON RIVER SYSTEM

Degrees of abundance of the species in each habitat occupied is indicated by: r = Rare; C = Common; A = Abundant.

SPECIES	LAKE SERIES 1–5					STREAM SERIES 6–14								
	Lakes Without Outlet		Lakes With Outlet			Brooks and Creeks			Rivers					
	Shoals All Soft	Shoals Partly Firm	Large Lakes	Chain Lakes	River-lakes	Brooks	Small Creeks	Larger Creeks	Small Rivers	Medium-Sized Rivers	Fairly Large Rivers	Large Rivers	Ponded Areas	Lower Rivers (Lake Influx)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Anodonta grandis	C	C	C	C	C	.....	.....	r	r	r	r	r	r	r
Lampsilis siliquoidea	.....	A	C	C	C	.....	.....	r	r	r	r	r	.....	.....
Strophitus rugosus	.....	.....	C	r	C	.....	C	C	C	C	r	.....	.....	.....
Lampsilis ventricosa	.....		r	C	C	.....	.....	.....	A	C	r	r	r	r
Elliptio dilatatus	.....	.....	.....	.....	r	.....	.....	C	A	A	A	r	.....	r
Lasmigona compressa	.....	.....	.....	.....	.....	C	A	C	C	r	.....	.....	.....	.....
Anodontoides ferussacianus	.....	.....	.....	.....	.....	r	A	C	C	.....	.....	.....	r	.....
Alasmidonta calceolus	.....	.....	.....	.....	.....	.....	A	A	r	r	.....	.....	r	.....
Micromya iris	.....	.....	.....	.....	r	.....	r	C	A	A	C	r	.....	r
Alasmidonta marginata	.....	.....	.....	.....	.....	.....	.....	r	C	C	r	r	.....	.....
Ptychobranchus fasciolare	.....	.....	.....	.....	.....	.....	.....	.....	A	C	C	r	.....	r
Lampsilis fasciola	.....	.....	.....	.....	.....	.....	.....	.....	A	C	C	r	.....	r
Dysnomia triquetra	.....	.....	.....	.....	r	.....	.....	.....	r	C	r	.....	.....	r
Ligumia recta latissima	.....	.....	.....	.....	.....	.....	.....	.....	.....	r	r	r	.....	r
Lasmigona costata	.....	.....	.....	.....	.....	.....	.....	.....	.....	C	r	r	.....	r
Cyclonaias tuberculata	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	A	C	.....	r
Anodonta imbecillis	.....	.....	.....	.....	.....	.....	.....	.....	r	.....	r	C	r	r
Lasmigona complanata	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	C	A	.....
Actinonaias carinata	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	C	.....	C
Micromya fabalis	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	C	.....	r
Fusconaia flava	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	C	.....	C
Carunculina parva	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	C	A	C
Quadrula pustulosa	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	r
Obovaria subrotunda	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	r
Ligumia nasuta	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	r

1.1.2 Threats to Unionidae

The overall decline of freshwater mussels can be attributed to a multitude of threats. Habitat alteration, pollution, climate change, invasive species and other environmental threats can reduce unionid reproductive capacity, decrease food availability, and cause mussel mortality.

Since mussels are sedentary animals, habitat alteration can be devastating to mussel populations. River impoundment limits the distribution of unionids because dams act as barriers to the dispersal of the fish hosts that mussels require for their glochidia (Tiemann, 2007; Pilger et al., 2012; Mulcrone & Rathbun, 2018; Badra, 2020). By restricting the movement of these fish hosts, mussel populations can be isolated from each other causing declines in genetic diversity, which is necessary for the long-term sustainability of mussel populations (Badra, 2020). Dams can also alter mussel assemblages by changing river habitats from lotic to lentic environments, which can be detrimental for species that are dependent on systems with flowing water (Tiemann, 2007). Similarly, the sedimentation that occurs from increasing siltation from dams can also be harmful for mussel populations because of the ensuing reduction in dissolved oxygen availability and substrate quality (Staton et al., 2000; Tiemann, 2007).

Invasive species are another major threat to unionid mussel populations. Zebra mussels (*Dreissena polymorpha*) were introduced to the Great Lakes in the 1980s through the ballast water of cargo ships and have devastated aquatic ecosystems in the region ever since (Mulcrone & Rathbun, 2018). The proliferation of zebra mussels is detrimental to unionids because they attach to the shell making it hard for the unionids to move, feed, and reproduce (Baker & Hornbach, 2000; Mulcrone & Rathbun, 2018; Badra, 2020). Abundant populations of zebra mussels then filter out the nutrients and food resources from the water that native mussels need.

Exotic Asian clams (*Corbicula fluminea*) and quagga mussels (*Dresissena bugensis*) can also reach high densities and compete with native unionids (Badra, 2020).

The filter feeding nature of mussels makes them especially susceptible to various forms of pollution. Organic pollution from herbicides, wastewater, and other industrial chemicals can cause toxicity in mussels, inducing oxidative stress, higher susceptibility to disease, reproductive dysfunction, genomic DNA damage, and an overall reduction in metabolism (Hassel & Farris, 2007). Nano-plastics ingested by mussels cause damage in the functional character of the gills as "brooding chambers" threatening their reproductive biology (Abdelsaleheen, 2023). Unionids can even suffer unintentional impacts from conservation strategies such as from poison applications for the control of other organisms like invasive sea lampreys (Gruber et al., 2012).

Their filter feeding behaviors make unionids vulnerable to parasites such as trematodes, which can hinder mussel growth, energy production and storage, and reproductive capacity (Zieritz & Aldridge, 2011; Abdelsaleheen, 2023). A wide variety of parasites including oligochaetes, nematodes, trematodes, watermites, and bitterlings can infest unionids and prevent their populations from recovering (Gillis & Mackie, 1994; McElwain et al., 2019; Taskinen, 2020).

Climate change and global warming pose threats to unionids because of their sensitivity to temperature changes. Since unionids must allocate their energy between regulating their valves for feeding and breathing, burrowing into the sediment, and occasionally moving, their survival is dependent on their metabolism (Abdelsaleheen, 2023). Mussels can vary in their tolerance to temperature change; however, increases in average temperatures due to global warming can present risks to mussels because of thermal stress reducing mussel growth, metabolic rate, and oxygen uptake (Payton et al., 2016; Abdelsaleheen, 2023). At temperatures

above 25℃, mussels may also cease the display of their reproductive lures or even expel their glochidia to relieve thermal and respiratory stress, which may prevent mussels from attracting fish hosts and reproducing successfully (Landis et al., 2012; Gibson, 2019).

1.1.3 Mussel conservation

While mussel populations have heavily declined, conservation measures can be effective at protecting and restoring remnant populations. Part 365 of the Endangered Species Protection Act of the State of Michigan, from the 1994 Michigan Natural Resources and Environmental Protection Act, details Michigan's definitions and protections for endangered species. This act defines endangered species as "any species of fish, plant life, or wildlife that is in danger of extinction throughout all or a significant part of its range" and threatened species as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range" (Legislative Service Bureau, 1994). Species are reviewed to be listed as threatened or endangered based on information including "population, distribution, habitat needs, limiting factors, and other biological and ecological data" (Legislative Service Bureau, 1994). Since 31 of Michigan's 43 species are currently listed as state or federally threatened, endangered, or special concern, there is substantial progress to be made.

The removal of old dams can be a significant tool to increase the access of mussels to host fishes. Removing dams can restore a lotic flow regime, connectivity with the rest of the watershed, the passage of fish, and dissolved oxygen flow all of which can be beneficial for mussel populations (McCombs, 2014). However, it should also be noted that ecological impacts of dam removal should be assessed to mitigate potential negative effects of desiccation and exposure, to relocate mussels from impact zones where reservoir deposits would be transported,

and to evaluate the potential of the dam removal to increase the spread of invasive species like zebra mussels and sea lamprey (Sethi 2004). The colonization and recovery of mussel populations in habitats where dams have been removed can also be slow, so continuous monitoring and management of those habitats is important to ensure the viability of these populations (Doyle et al., 2005). Thus, dam removal can be a powerful restoration measure with many different long-term and short-term impacts to consider.

Relocation can be an effective tool to use alongside dam removals or construction projects. Relocating mussels before dams are removed can prevent them from desiccation in the newly exposed habitat or from being buried by the deposited sediments. Impact avoidance measures, including relocation, are also currently required in Michigan for construction projects and dredging (Mulcrone & Rathbun, 2018). These relocation projects provide a unique opportunity for mussel surveys to be applied and to monitor how mussel populations are faring post-relocation.

Sedimentation and pollution reduction strategies can help to alleviate the impacts of excessive siltation and runoff. Riparian buffer zones can be effective at protecting streams from sediment inputs and pollutants (U.S. Fish and Wildlife Service, 2006). Rain gardens can also be implemented to filter out runoff for streams in more urban areas. These strategies paired with education on the application of harmful industrial products like herbicides can improve water quality conditions for mussels in streams near areas of human use.

Controlling the impact of nonnative mussels is a challenging yet important element of mussel conservation. Since zebra mussels have already contributed to the decline of many of the Great Lakes' native unionid populations, the protection of remaining refuges from zebra mussels is vital for the preservation of native unionids (Zanatta et al., 2002). Simple strategies to prevent

the spread of zebra mussels exist, such as inspecting and cleaning off any equipment that has been in contact with water including boats, waders, fishing gear, buckets, and other equipment.

The successful conservation of freshwater mussels is also dependent on the preservation of their fish host species. Fish species that are commonly used as hosts in the reproductive cycle of mussels in Michigan include large-mouth bass (*Micropterus salmoides*), small-mouth bass (*Micropterus dolomieu*), bluegill (*Lepomis macrochirus*), green sunfish (*Lepomis cyanellus*), rainbow darter (*Etheostoma caeruleum*), white crappie (*Pomoxis annularis*), long-nosed gar (*Lepisosteus osseus*), Orange spotted sunfish (*Lepomis humilis*), yellow perch (*Perca flavescens*), walleye (*Sander vitreus*), spotfin shiner (*Cyprinella spiloptera*), and state threatened lake sturgeon (*Acipenser fulvescens*) (Zanatta et al., 2007; Zanatta & Woolnough, 2011; Hnytka et al., 2022). Dam removal and the creation of fish passageways can help to improve the connectivity and movement of fish hosts throughout watersheds (Ferreira-Rodriguez et al., 2019). Protecting populations of these fish species so that they can move throughout the Huron River watershed carrying mussel glochidia can help to facilitate the growth and dispersal of mussel populations.

Lab propagation is a larger scale conservation measure that can also be used to reintroduce mussel populations into watersheds. Lab propagation can produce genetically diverse and viable juvenile unionids (VanTassel et al., 2021), and hatcheries have cultured and re-introduced juvenile mussels in watersheds in Missouri, Wisconsin, Minnesota, Arkansas, Tennessee, Georgia, Virginia, North Carolina, and Ohio (Neves, 2004; Eads et al., 2007). Current work being conducted with Central Michigan University and the Michigan Department of Natural Resources aims to create the first mussel propagation facility in Michigan, with

research focusing on the federally endangered snuffbox mussel (*Epioblasma triquetra*) (Woolnough, n.d.).

Along with these different conservation measures, the monitoring of mussel distribution is essential to know where populations exist and to effectively implement these restoration strategies. Volunteer mussel monitoring surveys pose as an apt opportunity to engage local communities in meaningful science to aid in the conservation of unionids.

1.2 Research goals and general approach

The purpose of this study is to design a volunteer program for the Huron River Watershed Council (HRWC) to guide the monitoring of freshwater mussels throughout the tributaries of the Huron River Watershed. Further, by engaging volunteers with unionids, we aim to increase public awareness and appreciation for mussels so the next generation of nature lovers and scientists will continue to care for and protect our Michigan mussels. HRWC already has several programs and projects that protect and restore other components of the watershed, such as macroinvertebrate water quality monitoring, water chemistry sampling, green infrastructure implementation, dam and impoundment assessment, river cleanups, and habitat restoration (Huron River Watershed Council, 2023). These other programs will benefit from the data obtained through the mussel surveys and from the connections made with volunteers and other organizations working with unionids.

2. Materials and Methods

2.1 Mussel survey training

I developed the mussel survey protocol to assess mussel abundance and species distribution in the Huron River Watershed based on available material and through experience with the survey protocols in the field. I used information from procedures developed by the Michigan Natural Feature Inventory (MNFI) (Hanshue et al., 2021). I obtained mussel survey training from Dr. Renee Mulcrone, a malacologist and aquatic biologist with over 25 years of experience in mussel research. Dr. Mulcrone is author to multiple publications on Michigan unionids (Mulcrone & Rathbun, 2020). Additionally, I consulted with numerous experts in the field, including personnel of the Michigan Department of Natural Resources and the Michigan Department of Environment, Great Lakes, and Energy.

I participated in two mussel surveys with Dr. Mulcrone. The first outing took place on September 17, 2022, at Riverside Park in Ypsilanti (Fig. 3). During this survey Dr. Mulcrone guided a high school student volunteer and I on a one-hour timed survey in the stretch of the Huron River located at 42.24475^{o} N, 83.61110^{o} W. I learned strategies to search for, collect, and handle mussels during this outing as we collected and identified live specimens of three species.

Figure 3. Mussels collected during the first survey at Riverside Park in Ypsilanti, MI. Live specimens of three species were collected, including eight female and one male wavy-rayed lampmussels (Lampsilis fasciola), four female and six male plain pocketbooks (Lampsilis cardium), and 1 female black sandshell (Ligumia recta). Dead shells were also collected for elktoe, Wabash pigtoe, and spike mussels.

The second mussel survey outing was on September 30, 2022, in the stretch of the Huron River under Whitmore Lake Road and the US-23 bridge at -42.471198º N, -83.756501º W. This survey was part of a contract job for the Michigan Department of Transportation (MDOT).It was in preparation for a construction project on the US-23 Bridge above the Huron River. For this project we conducted a transect survey to search for federally endangered snuffbox mussels that were to be relocated as an impact avoidance measure for the construction project.

I also was able to receive guidance for designing the program's survey protocol from experts from the Michigan Department of Natural Resources (MDNR). Cleyo Harris, a fisheries

technician for the Lake Erie Management Unit of the MDNR, was able to discuss with me the requirements and opportunities that would be possible for running a volunteer mussel monitoring program regarding what permits would be required and the level of involvement that volunteers could have. Additionally, I attended a presentation at the 2022 Annual MiCorps Conference by Joe Rathbun, a retired mussel biologist from the Michigan Department of Environment, Great Lakes, and Energy (EGLE), that discussed mussel survey protocol and species identification information (Rathbun, 2022). Joe Rathbun was also able to provide mussel species posters and brochures for HRWC volunteers to use.

Lastly, I used to construct my recommendations for HRWC's survey program the MNFI document "Michigan Freshwater Mussel Survey Protocols and Relocation Procedures for Rivers and Streams" (Hanshue et al., 2021). This document of protocols and procedures details instructions for how to conduct surveys, definitions of stream groups, and state and federal permit requirements.

2.2 Site selection

Potential sites were identified using the Michigan Mussels Web App from the Michigan Natural Features Inventory (Michigan Natural Features Inventory, n.d.), as well as past unionid survey studies in the Huron River conducted by Van der Schalie (1938) and Badra (2010). 85 sites have been identified throughout the Huron River Watershed. To provide recommendations for potential sites for the survey program, I selected 54 sites out of the 85 for a visit so to rank them; the other 31 sites were noted for future potential use but not ranked due to difficulty with access, private ownership of the site, or other complications. HRWC volunteers Larry Scheer and Matthew Paper assisted me in my site visits. Sites were recommended for volunteer mussel

surveys were selected based on factors of accessibility for parking, walking, and sampling access, substrate type, site ownership, and stream conditions (Appendix E).Further details for the site recommendation criteria are listed in Appendix E.

The most accessible and higher quality sites were recommended as primary sites (Fig. 4). Primary site recommendations consisted of streams with high accessibility for volunteers to park, walk to, and access streams, higher stream quality stable substrate for wading, and public ownership. Qualitative substrate measurements were collected through visual observations based on characteristics of rocks, sand, gravel, and mud. Sites were ranked higher if they had more space for volunteers to spread out in the stream so that larger volunteer groups would be able to participate in the survey. Locations that had multiple sections of the river close to each other that were suitable for volunteers to be split up into groups were also ranked as higher recommendations, especially for sites identified at public parks.

Figure 4. Example of a primary potential site in the Huron River at Riverside Park in Ypsilanti, MI. This site was listed as a primary recommendation due to high accessibility, high water quality, stable substrates, and public park access.

Secondary potential sites were also listed. These may be preferable for smaller teams or volunteers that are more willing to take more arduous walks to the site location (Fig. 5). These secondary sites typically were ranked based on lower parking availability, longer or more difficult walks through forested areas to the stream, and less accessible ways to enter a stream.

Secondary sites also may have lower water quality with a less probable chance of observing live mussels with more mucky streambeds that make wading more difficult.

Figure 5. Example of a secondary potential site in the Portage River tributary of the Huron River at Unadilla Rd in Unadilla, MI. This site was listed as a secondary recommendation due to deep water (~3 ft) and mucky substrate that could be less favorable for volunteers wading to search for mussels.

2.3 Permit application process

I researched the permit requirements for conducting mussel surveys and documented the application process for the Michigan Fisheries Cultural & Scientific Collector's Permit (Appendix B) and the Michigan Threatened/Endangered Species Permit (Appendix C) and went through the application.

I completed the application for the Michigan Collector's Permit at the following link: https://www.michigan.gov/dnr/managing-resources/fisheries/cultural-scientific-collectors-permit-fisheries. The application requires information on the type of activity being conducted, the applicant's institution or affiliations, contact information, a study plan for the activity, the species that are going to be collected, procedures for the survey/collection, and locations where surveys will be conducted. My application process for the Collector's Permit is documented in Appendix B.

The Michigan T/E Permit application form was obtained from the MDNR website at the following link: https://www.michigan.gov/dnr/-/media/Project/Websites/dnr/Documents/Forms/folder1/ES_Permit_Application.pdf?rev=0c6e1d833f0b4986abbaee1883dbb950&hash=CE8A13147BAD247399A4105176AD5238. This application asks for information similar to the Collector's Permit, but with a list of the state threatened or endangered species that are to be collected. A proposal letter is also required for new applicants for new applicants to state their qualifications, purpose and justifications for the activities, a list of species, and details of the project location, time, and methods. My application process for the Michigan T/E Permit is documented in Appendix C. After completing the application form, I submitted the application via email to the MDNR Wildlife Division permit

specialist, Casey Reitz (reitzc@michigan.gov). The permit application was approved two weeks after submission.

There is also a permit for federally listed T/E species that is issued by the US Fish and Wildlife Services (USFWS). However, since this permit takes up to a year to apply for and requires references and extensive mussel experience, I did not apply for this permit and instead researched information on the permit and identified local Michigan federally certified mussel experts that could help lead a survey if necessary.

Additionally, a permit is also required for conducting research in state parks. Although I did not apply for this permit, HRWC does already have knowledge of this permit for use in their other restoration activities.

2.4 Survey form

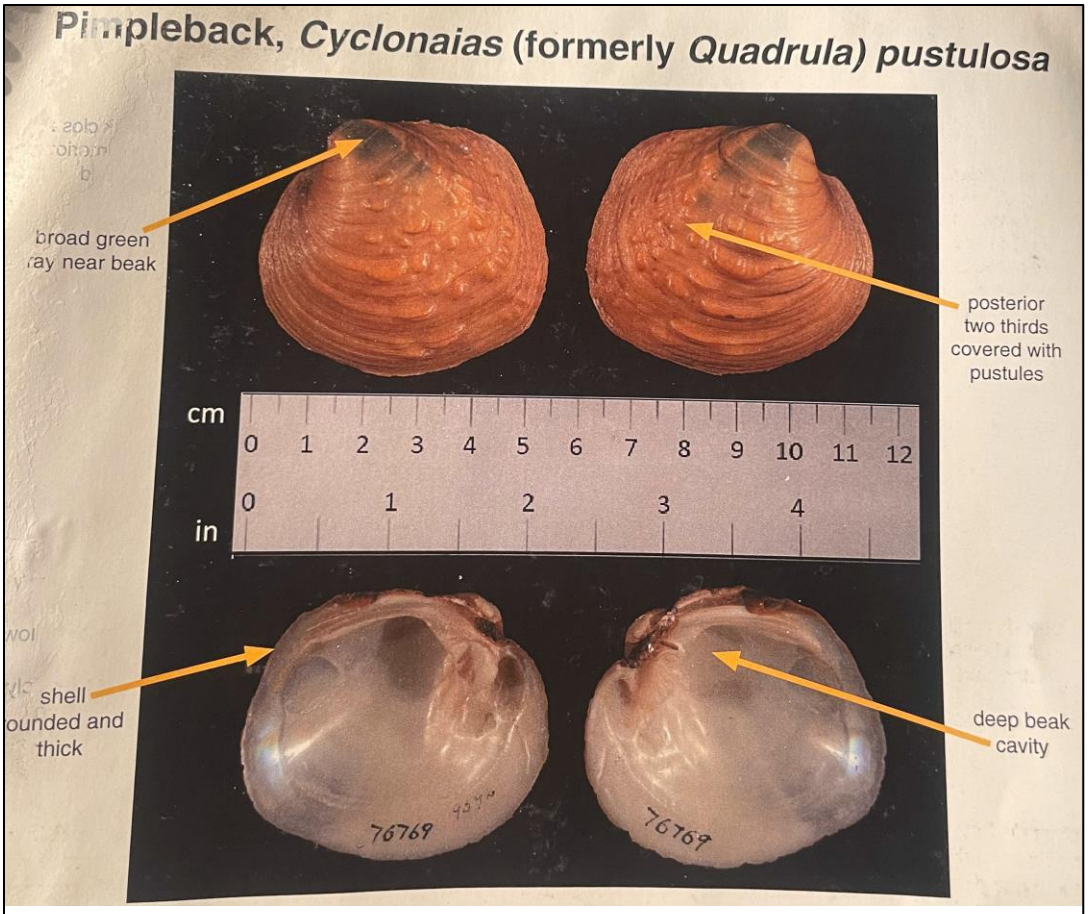
In addition to documenting the permit application process, I created a survey report form to be printed for the volunteers to record data for each survey (Appendix D). This survey report form was produced using information that must be included in an annual report for the Collector's Permit (https://survey123.arcgis.com/share/64d1ca86fb4f4655a2747237fbf2bb3b) and a report that must be completed for each T/E species at each site for the "Threatened/Endangered Species Report" (Appendix F).

2.5 Species identification materials

To inform the development of this program and the production of species identification materials I used the Field Guide to the freshwater mussels of Michigan (Mulcrone & Rathbun, 2018). I adapted a simplified set of species identification keys from this field guide for species

exclusively from the Huron River watershed that provides pictures and shell characters such as shape, color, and other features to aid volunteers with identifying species (Fig. 6).

Additional available material to training HRWC volunteers are posters and brochures of the freshwater mussels of Michigan (Fig. 7). These materials display photos of Michigan unionids with their common and scientific names as well as species identification information. The posters and brochures were created by Peter Badra of the Michigan Natural Features Inventory and were funded by the MDNR, EGLE, and USFWS.



Pimpleback, *Quadrula pustulosa*

Size: up to 10 cm (4 in)

Shape: round and thick; shell varies from compressed to moderately inflated

Color: light brown

Rays: one broad green ray near beak; broken green rays in juveniles

Additional features: 2/3 of posterior end is covered with pustules

Figure 6. Example of a species description for pimpleback (Quadrula pustulosa) from the Field Guide to the freshwater mussels of Michigan (Mulcrone & Rathbun, 2018). Description lists size, shape, color, presence of rays, and any other helpful additional shell characteristics to aid in species identification.

Figure 7. Poster "Freshwater Mussels of Michigan" created by Peter Badra (2020), Photos of the shells were taken from specimens from the University of Michigan Museum of Zoology and Dr. David Zanatta from Central Michigan University.

2.6 Production of 3D models

Since mussel shells are difficult to acquire for use as references in species identification due to permitting restrictions, I selected a set of 16 common species from Huron River, to create training 3D printed models. These species are those that volunteers would most probably find during surveys. To create the models, I collaborated with Syrena Kapsa and other personnel at CultureVerse, an Ann Arbor based non-profit. Their mission is to serve the community by expanding opportunities to access and experience projects, storytelling, and creative expression of artists, educators, students, and preservationists. They provide technology, training, consultation, and other resources (www.cultureverse.org). Specimens from unlisted species were loaned from the University of Michigan Museum of Zoology Mussel Mollusk Collection (University of Michigan LSA Museum of Zoology, n.d.). These museum specimens were scanned with a Shining 3D EinScan-SP scanner (Fig. 8) using the software EXScan S (Fig. 9). On average each specimen took about 45 minutes to an hour to complete a scan, however, specimens with shells that were shinier, more compressed, and had more holes or rough textures took up to two hours to get a complete scan. The models were then printed using a Prusa i3 MK3 3D printer, taking around 10 hours per model to print (Fig. 10).

I then painted the printed 3D models to resemble the coloration of live specimens. I first sprayed the models with a coat of gray ColorMaxx primer to produce a smooth surface on the models for painting. After letting the coat of primer dry, I painted the models with acrylic paint using images of live specimens for each species as references. Lastly, I finished the models with a coat of Liquitex gloss varnish as a protective layer.

A virtual gallery is also being developed where the scans of the 3D models will be displayed online for volunteers and the public to view. The virtual gallery will have the mussel

scans displayed with annotations of species characteristics and with general information provided about unionids and the monitoring program. It is created in the 3D model viewing platform Sketchfab (Fig. 11).

Figure 8. Scanning a pink heelsplitter (Potamilus alatus) using a Shining 3D EinScan-SP scanner at CultureVerse.

Figure 9. Screen capture of a scanned fat mucket (Lampsilis siliquoidea) in the Shining 3D software "EXScan S.

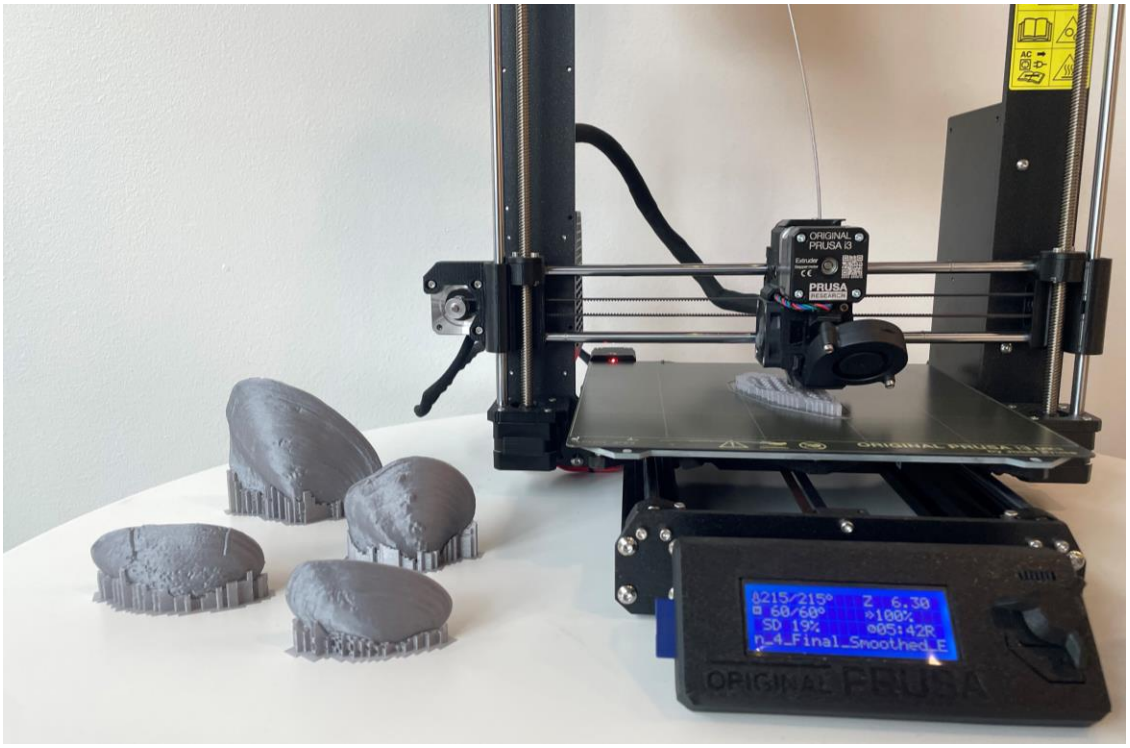


Figure 10. Prusa i3 MK3 3D printer starting to print a new 3D model to the right, with four completed 3D models to the left.

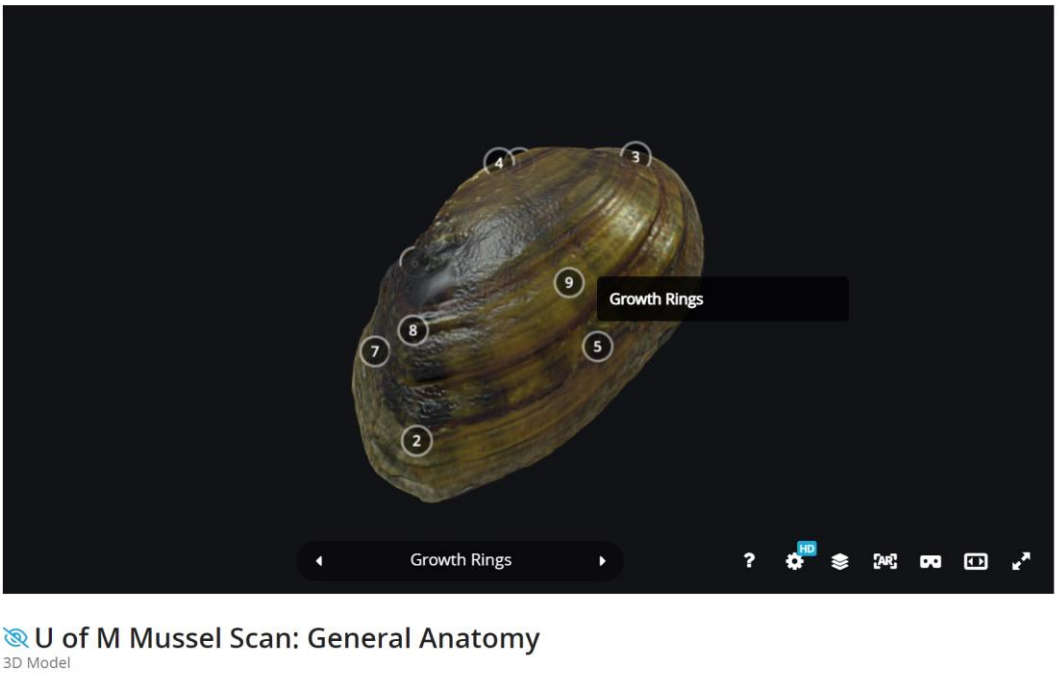


Figure 11. Example of a mussel scan that with annotated shell characteristics in Sketchfab to aid in species identification. A scan of a mucket (Actinonaias ligamentina) is depicted in this image.

2.7 Digital painting of mussel mural

For use in spreading awareness about unionids and the monitoring program, I digitally painted a mural of a mussel's life cycle. I created this digital painting in the free graphic editing software Krita. The mural follows the reproductive strategy of a plain pocketbook (*Lampsilis cardium*) and a bluegill (*Lepomis macrochirus*) as its fish host. The mural will also be placed in the virtual gallery and used to spread awareness about unionids and the mussel monitoring program.

3. Results - Program Design

The proposed citizen science program for HRWC consists of volunteer mussel monitoring surveys to observe and count the species diversity and abundance of mussels across sites in the Huron River watershed. Also included in the program design are requirements for the required permits that survey leaders must acquire to conduct the activities.

3.1 Mussel survey protocol

The surveying season for mussel monitoring should take place from summer to early fall, around June 1 to October 15, when water temperatures are greater than 10°C. Conditions should be such that it is warm enough for more mussels to be near the surface and the water level is low enough for surveyors to wade safely (Rathbun, 2022). Recommendations for suitable monitoring days include a depth of water transparency of about 1 ft., and water flow speeds that are safe for wading.

At the start of each survey, site habitat details including the area of the stream being surveyed, water flow speed, and water depth should be recorded. Volunteers can be separated into two teams based on interest and ability to enter the water. The field team will consist of volunteers wading in the stream to search for and gather mussel specimens, while the dry team will include those who cannot or would not like to enter the water, instead staying on the stream bank to help sort mussel species. A few more experienced or willing members of the dry team can also be appointed as liaisons to answer questions from any passersby. Site specific data that is collected from each survey is considered valid for 5 years after the monitoring date (Hanshue et al., 2021). Thus, sites should be monitored at least every 5 years. More frequent monitoring can be scheduled when required in conjunction with other projects such as relocation.

3.1.1 Survey format

Surveys can have one of two formats based on the purpose of the survey: timed surveys and transect surveys.

Timed Surveys: For most general volunteer events, a timed survey is recommended. In the timed survey, a section of the stream is identified and marked (i.e., from one identified tree to another tree). The group will spend a set amount of time (at least 60 minutes) to sample throughout that section of the stream collecting mussels. The collected specimens are to be identified and counted by number of individuals per species. The total number of specimens and number per species are to be recorded. Afterwards the mussels are returned to the stream and equipment is cleaned. Unless a highly skilled mussel expert is with the team, the team will photograph each individual mussel in at least three different angles before returning it to the water (Fig. 12). Photographs should be labeled with the name of the stream each mussel specimen was collected from and the date of the survey. As the mussels are placed back into the stream, it is essential to ensure that they are positioned correctly as to not suffocate them; by placing mussels flat against the bottom of the stream so they will be able to reposition themselves without volunteers having to be concerned about the correct placement orientation (Fig. 13).

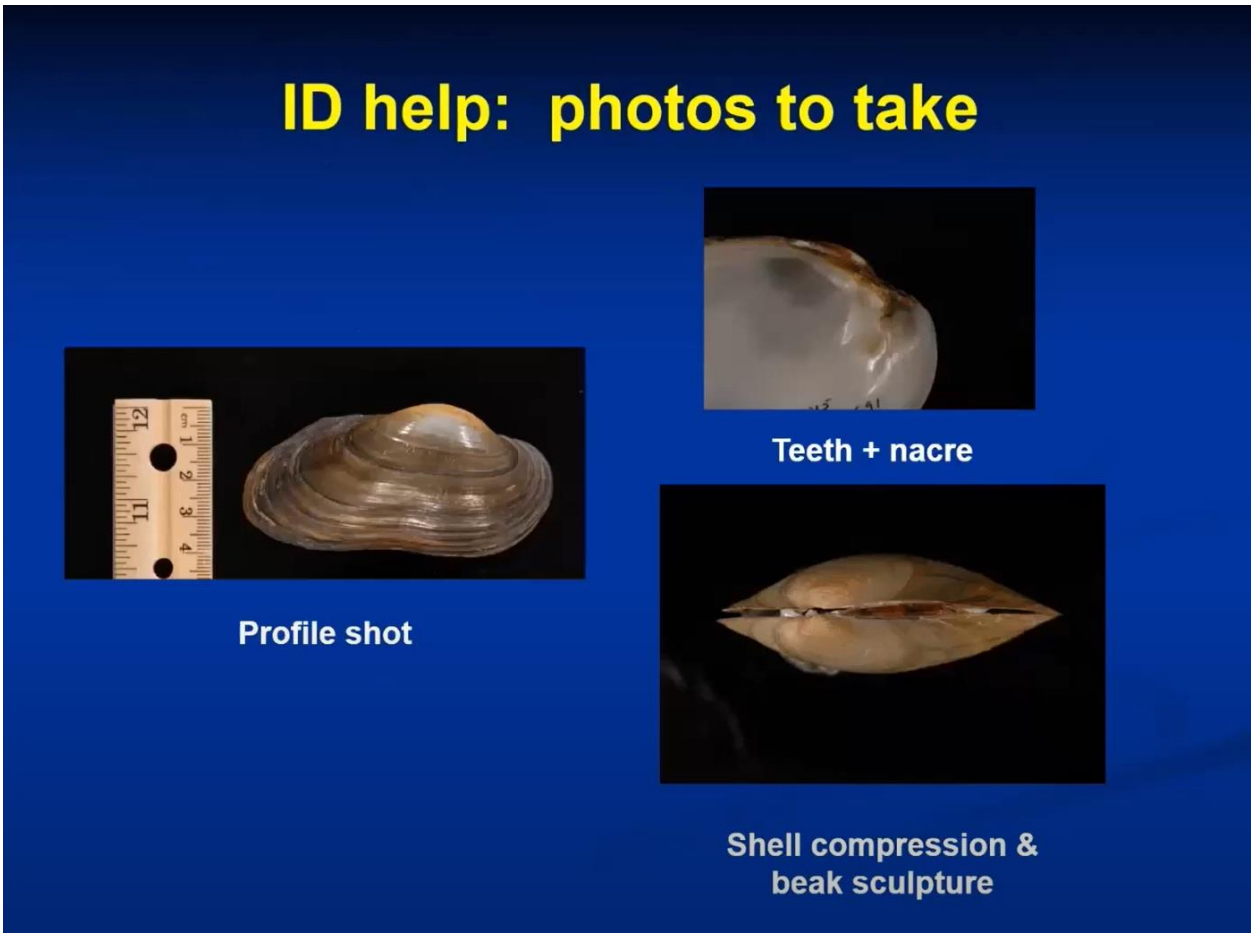


Figure 12. Photograph angles to take for species identification during mussel monitoring surveys, taken from Rathbun (2022). Ruler measurements are not required to include in photos but may help to validate the identification of species after a survey if necessary.

Figure 13. Photographs of the orientation in which mussels should be returned to the river. This allows the mussels to reposition themselves, so they do not suffocate.

Transect survey format: The transect method is recommended for surveys that are being conducted for specific purposes, such as in conjunction with other restoration projects or for relocation before small-scale construction projects for structures like bridges and pipelines. While this method is more time and energy consuming, it is preferable over the timed method for these specific projects as it is more effective at finding every species and individual mussels present in the stream. Most instances where the transect method is used will be for projects where volunteers help personnel from the MDNR, MDOT, etc., and so in those contexts their instructions supersede the recommendations provided here.

For this method, the area of concern in the stream is divided up into transects of ten meters placed perpendicular to stream flow. As per MNFI recommendations: “Transect spacing

in small and medium rivers (drainage area less than 300 square miles) should not exceed 10 m and in large rivers transects will be spaced 25 m apart." (Hanshue et al., 2018). Accordingly, in surveys in the main branch of the Huron River, transects should be spaced 25 m apart, and in surveys in the smaller tributaries of the Huron River, such as Portage Creek, Mill Creek, Honey Creek, and Fleming Creek, transects should be spaced less than 10 m apart. Each transect is searched thoroughly multiple times with a minimum of 30 seconds/m^2 to find all mussels present in each transect. In instances where the transect method is being used to survey for mussels before construction projects, additional instructions and requirements may also be given on a case-by-case basis according to the MDNR and USFWS.

3.1.2 Survey procedures

(*skip step 2 for timed surveys)

1. a) Record site habitat information: this includes water flow speed, water depth, substrate type, and GPS location b) take photos of the site (Appendix D). c) Record the name(s) of the survey leader(s) and the date of the survey.
2. Set up 10m survey transects in stream along area of concern if using the transect method. The number of transects will depend on the site and the details of what areas of the river the construction project will impact. *
3. Start a timer or record the time when the survey starts to record how long the survey lasted to gauge surveying effort.
4. Collect live mussels and dead shell material and place in mesh bags or buckets to carry under water. Mussels should always be kept cool and wet, minimizing the time they are out of water.

5. Spread volunteers out in the stream to get samples across the site and prevent any rocks or sediment from getting kicked downstream into another volunteer. Surveyors should stay in shallow areas to ensure safety.
6. Keep mussels wet after collection by laying them out over a surface (such as mesh bags) in shallow water at the bank of the stream, or in large trays with stream water.
7. Take photos of live and dead specimens and identify, count, and record species. Use field guides, 3D models, and survey leader knowledge (Appendix D). Dead shells may only be collected according to the survey leader's scientific collector's permit.
8. When returning mussels to the stream after collection and identification, place them flat to allow them to reorient themselves and not suffocate the mussels.
9. Clean all equipment after the survey has concluded to avoid spreading pathogens or invasive species between streams.

3.3 List of recommended equipment

Figure 14. Glassbottom bucket used to search underwater for mussels: Marine Sports Underwater Viewer from Cabela's, at https://www.cabelas.com/shop/en/marine-sports-underwater-viewer.

*Figure 15. Regular buckets or trays to hold mussel in water to carry to streambank for species identification. United Solutions 5 Gallon Bucket from Amazon. **

Figure 16. Mesh collection bag to hold mussels, from Amazon.

Figure 17. Waders to enter streams. White River Fly Shop Montauk Stocking-Foot Chest Waders, from Cabela's.

Figure 18. Digging tools to scoop mussels that are burrowed in sediment. Garden Guru Super Strong Garden Scoop from Amazon.

Figure 19. Waterproof gloves for pulling mussels from the water. Carhartt Mens Thermal Wb Waterproof Breathable Nitrile Grip Glove from Amazon:

Figure 20. Pack of stake markers to outline transects from Amazon

Figure 21. Depth gauge or stick to record depth of stream. Snowbee Telescopic Wading Staff with Depth Markers from https://www.snowbee.co.uk/snowbee-telescopic-wading-staff-with-depth-markers.html

Figure 22. Water velocity meter/thermometer to measure water flow speed and temperature. FM-100V5 Portable Velocity Flow Meter from Amazon.

Additional equipment:

- Field guides (Appendix G), posters, and brochures with species identification information (Fig. 7). Copies of these posters were obtained for HRWC from Joseph Rathbun (rathbunj@sbcglobal.net).
    - Full field guide (Mulcrone & Rathbun, 2018)
    - Smaller pocket field guide (Mulcrone & Rathbun, 2020)
- 3D models as visual aids for identifying unlisted unionid species (Fig. 11)
- GPS unit (on smartphones) to track and record site location coordinates

3.4 Site locations

Out of the 46 sites ranked for recommendations for the volunteer monitoring program (Fig. 23), 31 were recommended as primary sites (Table 2) and 15 were recommended as secondary sites (Table 3). These sites include locations in four Michigan counties in the Huron River Watershed (Washtenaw, Wayne, Oakland, and Livingston) that span across the main branch of the Huron River and seven branching tributaries (Pettibone Creek, Portage Creek, Fleming Creek, Mill Creek, Livingston Country Honey Creek, Washtenaw County Honey Creek, and Woodruff Creek) and represent a variety of habitats that range from urban to rural and vary between substrate types (i.e., rock, gravel, sand, and mud). Nine of the visited sites were not recommended for the survey program because of difficult access to the site or stream, poor habitat quality, and/or low probability of mussel presence.

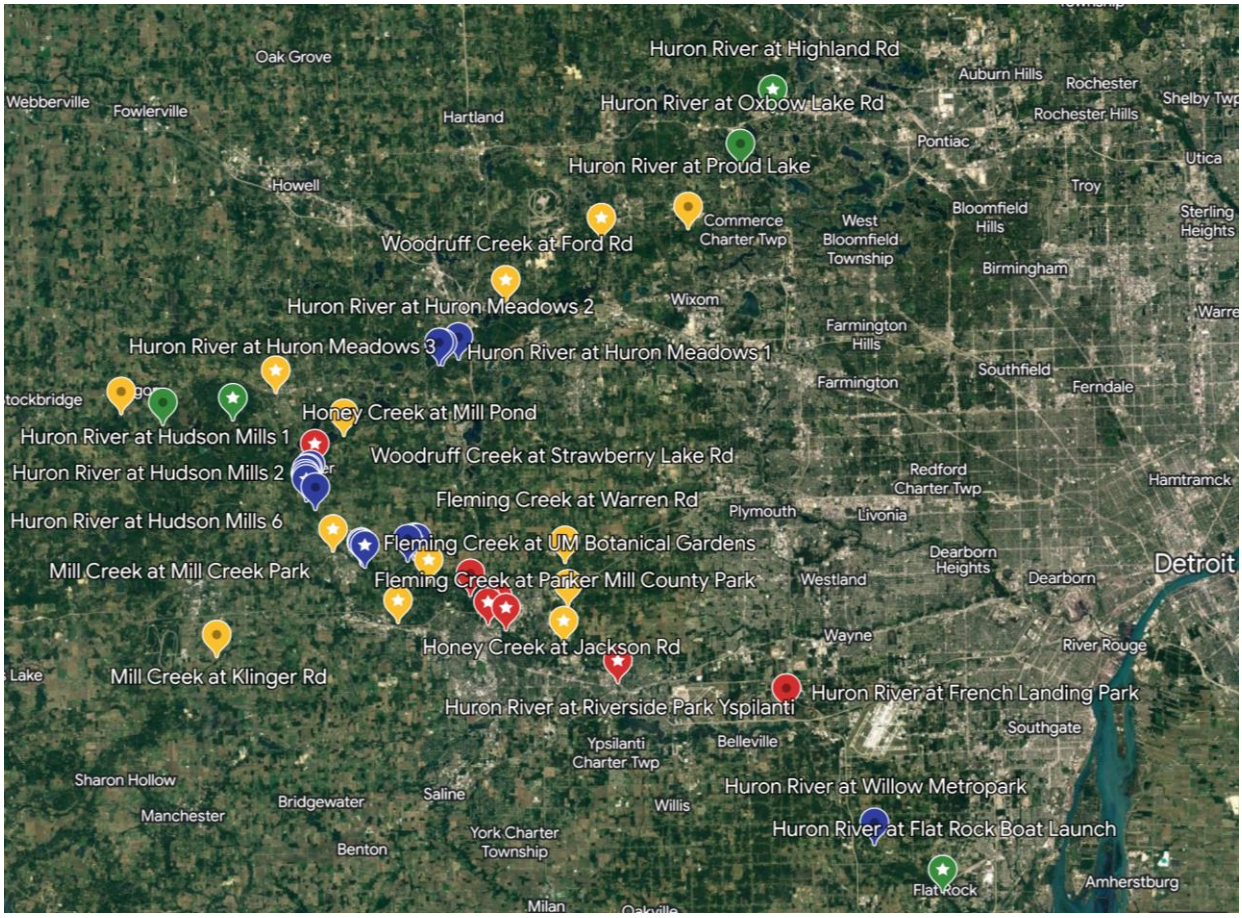


Figure 23. Map of recommended sites in the Huron River Watershed. Marker color indicates stream group and permit requirement (Green = Group 1: Collector's permit, Yellow = Group 2: State T/E permit, Red = Group 3: Federal T/E permit, Blue = Michigan State Park: Federal T/E permit and state park land use permit). Stars indicate primary recommended sites. Secondary recommended sites do not have a star. Map created in Google Earth.

Table 2. Primary sites recommended for the volunteer mussel monitoring surveys in the Huron River Watershed. Required permit to conduct a survey is given for each site: Stream Group 1= Collector's Permit, 2 =State T/E permit, and 3 =Federal T/E permit . Sites are named by the corresponding stream and a nearby landmark (e.g., road or park). GPS are given coordinates for the stream location. Further information for each site and how sites were selected can be found in Appendix E.

Stream Group	**Stream Name**	**GPS Coordinates**
1	Huron River at Flat Rock Boat Launch	42°05'32"N 83°17'36"W
1	Huron River at Highland Rd	42°39'27"N 83°27'26"W
1	Pettibone Creek at E Livingston Rd	42°38'18.0"N 83°54'24.0"W
1	Portage Creek at Hiland Lake Dam	42°26'02.5"N 83°59'20.7"W
2	Fleming Creek at Parker Mill County Park	42°18'00.0"N 83°39'35.3"W
2	Fleming Creek at UM Botanical Gardens	42°16'23.9"N 83°39'50.4"W
2	Fleming Creek at Warren Rd	42°19'53.4"N 83°39'45.7"W
2	Honey Creek at Jackson Rd	42°17'16.4"N 83°49'34.7"W
2	Honey Creek at Mill Pond	42°27'14.5"N 83°56'49.2"W
2	Honey Creek at N Wagner Rd	42°19'02.3"N, 83°47'46.7"W
2	Huron River at W Dawson Rd	42°33'54.0"N 83°37'37.2"W
2	Huron River at Wixom Rd	42°34'26.6"N 83°33'32.3"W
2	Mill Creek at Mill Creek Park	42°20'21.8"N 83°53'24.7"W
2	Woodruff Creek at Ford Rd	42°31'10.8"N 83°43'15.2"W
2	Woodruff Creek at Strawberry Lake Rd	42°25'39.0"N 83°52'57.0"W
3	Huron River at Bell Rd	42°24'04" N, 83°54'30" W
3	Huron River at Delhi Metropark 1	42°19'59.6"N 83°48'28.8"W
3	Huron River at Dexter-Huron 1	42°19'48.0"N 83°51'44.8"W

3	Huron River at Dexter-Huron 2	42°19'44.7"N 83°51'41.0"W
3	Huron River at Dexter-Huron 3	42°19'40.3"N 83°51'32.2"W
3	Huron River at Hudson Mills 1	42°23'09.6"N 83°54'44.0"W
3	Huron River at Hudson Mills 2	42°23'00.4"N 83°54'53.8"W
3	Huron River at Hudson Mills 3	42°22'57.3"N 83°54'59.2"W
3	Huron River at Hudson Mills 4	42°22'45.5"N 83°55'03.9"W
3	Huron River at Hudson Mills 5	42°22'39.8"N 83°55'00.3"W
3	Huron River at Hudson Mills 6	42°22'32.2"N 83°54'59.6"W
3	Huron River at Huron Meadows 1	42°28'26.8"N 83°46'59.4"W
3	Huron River at Island Park	42°17'27.9"N 83°43'42.3"W
3	Huron River at Nichols Arboretum	42°16'58" N, 83°43'14"W
3	Huron River at Riverside Park Ann Arbor	42°17'12.1"N 83°44'03.8"W
3	Huron River at Riverside Park Yspilanti	42°14'40.2"N 83°36'39.6"W

Table 3. Secondary recommended sites for volunteer mussel monitoring surveys in the Huron River Watershed. Secondary sites are identified as streams that may be harder to access and may need a more experienced or physically capable survey crew. Additional information for each site and how sites were selected can be found in Appendix E.

Stream Group	**Stream Name**	**GPS Coordinates**
1	Huron River at Huroc Park	42°05'44"N 83°17'48"W
1	Huron River at Oxbow Lake Rd	42°37'07"N 83°29'24"W
1	Portage Creek at Unadilla Rd	42°25'50.2"N 84°03'28.3"W
2	Huron River at Proud Lake	42°34'23.0"N 83°32'30.0"W
2	Mill Creek at Klinger Rd	42°15'45.7"N 84°00'14.0"W

2	Portage Creek at Williamsville Rd	42°26'18"N 84°05'56"W
3	Huron River at Huron Meadows 2	42°28'28.5"N 83°47'11.8"W
3	Huron River at Huron Meadows 3	42°28'42.2"N 83°46'05.0"W
3	Huron River at Barton Dam	42°18'27.1"N 83°45'19.4"W
3	Huron River at Delhi Metropark 2	42°20'01.0"N 83°48'38.0"W
3	Huron River at Delhi Metropark 3	42°19'57" N, 83°49'01" W
3	Huron River at French Landing Park	42°12'57" N, 83°26'24" W
3	Huron River at Hamburg Rd	42°27'54.7"N 83°48'00.4"W
3	Huron River at Hudson Mills 7	42°22'09.9"N 83°54'28.3"W
3	Huron River at Willow Metropark	42°07'36.0"N 83°21'36.0"W

3.4 Permit requirements and instructions

Because of the conservation status of freshwater mussels in Michigan with many species deemed threatened or endangered (T/E), there are protections on how people can interact with them that vary depending on the status of the species. Three levels of permits are issued by the MDNR Fisheries Division and the USFWS for mussel surveying: Fisheries' Cultural or Scientific Collector's Permit, a state MDNR T/E permit, and a federal USFWS T/E permit. The restrictions for each permit can also be organized into three groups based on potential occurrence of T/E species (Fig. 24). Group 1 streams are likely to support Michigan species that are common or Special Concern, which is a designation that identifies a species' vulnerability to becoming threatened (Hanshue et al., 2021). Group 2 streams are likely to support State T/E species, while Group 3 streams support federally listed species (Hanshue et al.). Group number designations for each stream are determined using known species distributions, state and federal

protection status, and habitat suitability for each species based on substrate and stream hydrology (MNFI, n.d.).

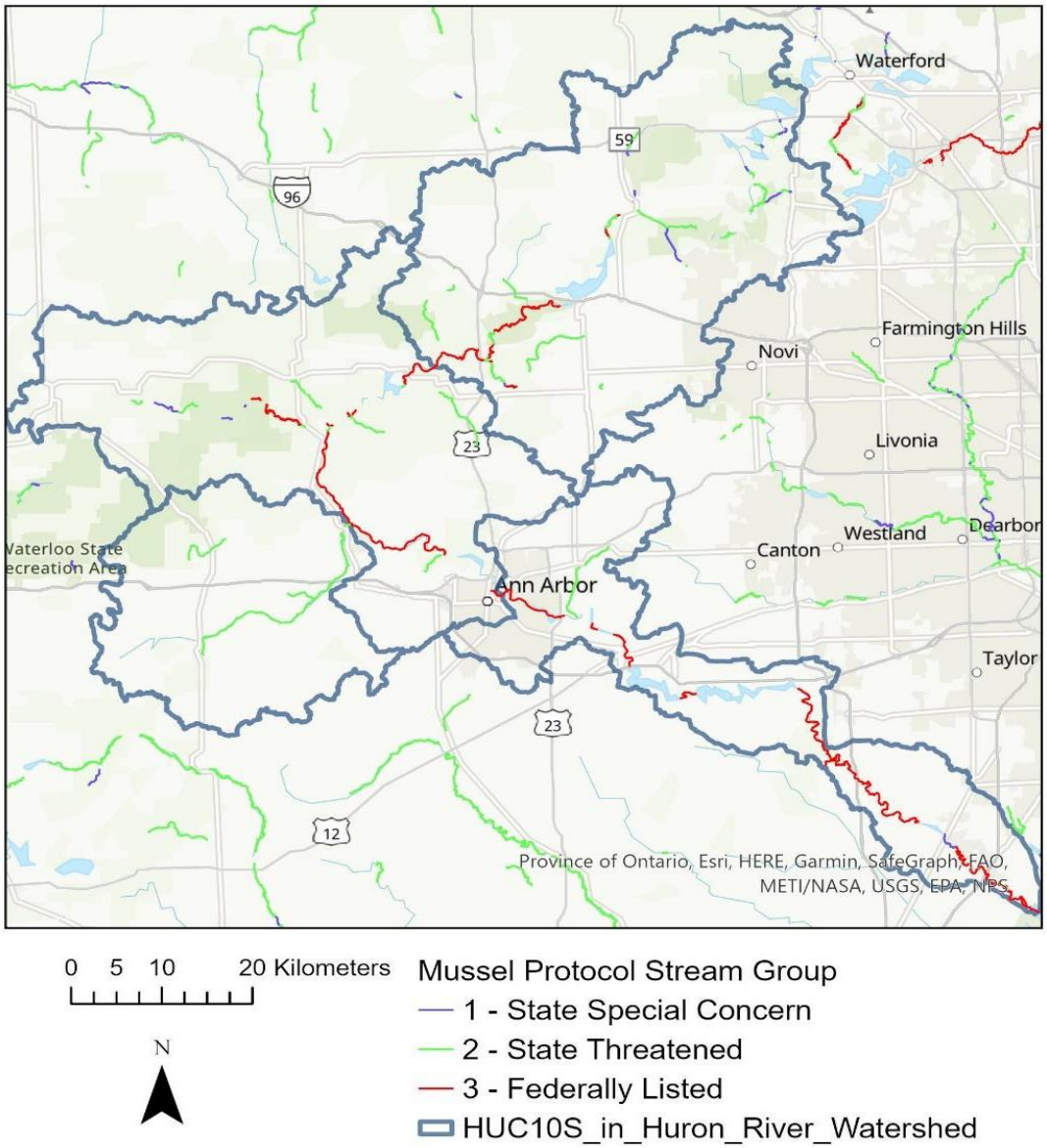


Figure 24. Map of the Huron River Watershed stream groups organized by color (Group 1: Blue, Group 2: Green, Group 3: Red). Streams that are not shown do not have recent information. Taken from Michigan Natural Features Inventory (n.d-b). The Michigan Mussels Web App created by MNFI can be accessed at: https://mnfi.maps.arcgis.com/apps/webappviewer/index.html?id=3860be5d7f28471396d44e0b384abb12.

A Fisheries' Cultural or Scientific Collector's Permit allows its holder to handle, collect, possess, or oversee the surveying of non-T&E freshwater mussel species in Michigan (Hanshue et al., 2021). A survey leader must have a Collector's Permit on site to lead a mussel survey for HRWC (Appendix B). Survey leaders with this permit are most likely to be individuals that already have experience with mussel identification and handling. Volunteers who participate in surveys are not required to have a permit if a permitted survey leader is present and can help search for and collect mussels under the guidance of the survey leader. No paperwork is required by MDNR from individual volunteers to participate in surveys. Volunteers who desire to lead a survey may eventually work to become survey leaders and apply for a permit after gaining experience with mussel identification. A Collector's Permit is required for a survey leader working in Group 1 Streams with no T&E species expected; beyond Group 1 a higher certification is also required. If a T/E listed specimen is found during a Group 1 Stream with a group leader who does not have a state or federal T/E permit, the survey must immediately end after notifying the MDNR, and all specimens must be returned to their collection site.

A State T/E Permit from the MDNR Wildlife Division is required for Group 2 streams in addition to the Collector's Permit. The application for this permit (Appendix C) should be emailed or mailed to the MNDR Wildlife Division permit specialist, currently Casey Reitz (reitzc@michigan.gov), at 525 West Allegan St., P.O. Box 30444, Lansing, MI 48909-7944. This permit allows surveys to be conducted in Group 2 streams where state T/E species are likely to be present.

Federal T/E permits are required for the survey leader surveying Group 3 Streams where federally listed T&E species have been observed or are expected (Hanshue et al., 2021). Section 10(a)(1)(A) federal T/E permits are issued by the USFWS and are typically reserved for experts

in the field that have acquired years of experience studying mussels (Pruden & Hanshue, 2017). In cases where a potential survey leader has documented field experience, a Bachelor of Science degree in a related biology or environmental science field, and sufficient knowledge of mussels alongside species identification skills, they can apply for the federal permit, named 3-200-59: Scientific Purposes, Enhancement of Propagation, or Survival Permits (Recovery Permits). This federal Recovery Permit can be obtained by creating ePermits and Login.gov accounts through this site (https://www.fws.gov/service/3-200-59-scientific-purposes-enhancement-propagation-or-survival-permits-recovery-permits) and by contacting the East Lansing USFWS office's Endangered Species Coordinator at (517) 351-2555. Otherwise, surveys planned by HRWC that are located in Group 3 Streams must have federally certified mussel experts, which as of 2023 include: Dr. Renee Mulcrone, Dr. Joseph Rathbun, Dr. David Strayer, Peter Badra (MNFI), Amanda Chambers & John Matousek (EGLE), and Jeff Grabarkiewicz & Dave Dortman (MDOT). Mussel surveys can proceed with one of these federally certified survey leaders present and uncertified volunteers can help search for mussels and collect/handle mussel specimens.

Additionally, a state park land use permit is also required for conducting mussel surveys in state parks and recreation areas. The application for this land use permit can be found at: https://www.michigan.gov/dnr/managing-resources/public-land/permission/scientific. The application consists of general information about the mussel surveys' locations, purpose, and activities, as well as a separate research proposal that documents the proposed study details, a schedule of the field season, and the needs and impact of the research being conducted (Michigan Department of Natural Resources, n.d.). Alicia Ihnken, a MDNR stewardship analyst and research coordinator, can be contacted for additional information about this permit at IhnkenA@michigan.gov.

3.4.1 Survey reporting

Survey plans must be provided to the MDNR for all stream groups (and additionally USFWS for Group 3 streams) at least 15 days in advance for review and approval of appropriate survey protocols (Hanshue et al., 2021). To coordinate with the MDNR, the Lake Erie Management Unit Fisheries Division supervisor must be notified. The current MDNR Fisheries Biologist is John Buszkiewicz, who can be contacted at buszkiewiczj@michigan.gov and (248) 296-2498. A copy of a set work schedule can also be provided to the MDNR for an entire field season in place of additional contacts for each survey. For Group 3 stream surveys, the USFWS Michigan Field Office in East Lansing must also be notified at (517) 351-2555 to give approval for the project. Permits must be in possession on site during each survey (Appendices B & C).

For state T/E species, an annual "Threatened/Endangered Species Report Form" must be completed at the end of each calendar year by January 31st for each species at each Group 2 or 3 site, to be submitted via email to the MDNR Wildlife Division Permit Specialist, currently Casey Reitz reitzc@michigan.gov (Appendix F). This annual report must be completed even if no listed species were observed or collected during that year. Any new occurrences of state T/E species found in streams where they have not previously been observed or expected, i.e., in Group 1 streams, should be reported as soon as possible to the MDNR Permit Specialist. A Threatened/Endangered Species Report Form must also be submitted within 10 days of the state T/E permit expiration date, including information on every location where T/E species were observed throughout the duration of the permit. For federal T/E species, reports will have to be completed by the federally certified expert leading the survey.

As per requirements for the Scientific Collector's permit, an annual report must also be submitted to the MDNR at the end of each year before permit expiration on December 31

detailing the surveys that were conducted, using the report at the following online link: (https://www.michigan.gov/dnr/managing-resources/fisheries/cultural-scientific-collectors-permit-fisheries). The annual report must include the collector's permit information, the date and location of the surveys that were conducted, and the number of specimens and name of species that were handled. This report must be completed even if no mussels were observed or handled during that year. Site specific data that is collected from each survey is considered valid for 5 years after the collection date (Hanshue et al., 2021).

4. Results – Educational Materials

I produced and acquired a set of informational materials that can be used in species identification, environmental education, and spreading awareness about mussel conservation. These materials include species identification keys I adapted from a field guide, brochures and posters I collected, a set of 3D models, a virtual gallery that is in process to be produced, and a digitally painted mussel mural.

4.1 Species identification

The species identification keys that I developed as a simplified version from a field guide (Mulcrone & Rathbun, 2018) with species descriptions for mussels specific to the Huron River watershed, information on species descriptions, habitat preferences, state and federal status, as well as pictures to help with species identification are in Appendix G.

Volunteers looking to become survey leaders after gaining enough experience handling and identifying mussels should also take the Michigan Chapter of the American Fisheries Society and MDNR Freshwater Mussels Identification Test to help with their certification. This test was intended for for-profit businesses and consulting firms looking to do projects and is currently a recommendation not a requirement for volunteer surveyors (Rathbun, 2022). Applicants can take this test at no cost, with two testing opportunities planned for 2023 in the summer at Lake Superior State University and in the fall at the University of Michigan. The test covers species identification for adult specimens of 41 native Michigan species. Interested applicants can register for this test at (https://michigan.fisheries.org/annual-meetings/upcoming-meeting/) and David Strayer can be contacted for more information (strayerd@caryinstitute.org).

4.2 Set of 3D models

I produced a set of 3D models for the common Huron River species in collaboration with CultureVerse (Fig. 25; Fig. 26; Fig. 27). The 16 species scanned for this set included cylindrical papershell (*Anodontoides ferussacianus*), creek heelsplitter (*Lasmigona compressa*), pink heelsplitter (*Potamilus alatus*), spike (*Eurynia diltata*), fragile papershell (*Leptodea fragilis*), giant floater (*Pyganodon grandis*), threeridge (*Ablema plicata*), fat mucket (*Lampsilis siliquoidea*), white heelsplitter (*Lasmigona complanata*), plain pocketbook (*Lampsilis cardium*), pimpleback (*Cyclonaias pustulosa*), fluted-shell (*Lasmigona costata*), Wabash pigtoe (*Fusconaia flava*), creeper (*Strophitus undulatus*), mapleleaf (*Quadrula quadrula*), and mucket (*Actinonaias ligamentina*). This set of models will aid in species identification and volunteer training, since permitting restricts the collection of live or dead specimens from the field. These 3D models will also be available to view online in an online gallery that is being developed with CultureVerse.

Figure 25. Pictures of me painting a 3D model of a pimpleback (Cyclonaias pustulosa).

Figure 26. Photograph of a *painted 3D model of pink heelsplitter (Potamilus alatus) to the left, with the specimen from the University of Michigan Museum of Zoology Mollusk Collection to the right used to create the model.*

Figure 27. Photograph of 10 painted 3D models. Species depicted include from left to right, top to bottom plain pocketbook (Lampsilis cardium), threeridge (Ablema plicata), mucket (Actinonaias ligamentina), spike (Eurynia diltata), pink heelsplitter (Potamilus alatus), pimpleback (Cyclonaias pustulosa), mapleleaf (Quadrula quadrula), cylindrical papershell (Anodontoides ferussacianus), fragile papershell (Leptodea fragilis), and creek heelsplitter (Lasmigona compressa).

4.3 Mural of Unionidae life cycle

I also created a mural that illustrates the life history and reproduction strategies of unionids (Fig. 28). In the mural, there is a plain pocketbook (*Lampsilis cardium)* displaying its lure to attract a bluegill host. The image shows the reproductive cycle from left to right as the bluegill swims upstream. At the very left, a male pocketbook is shown releasing its sperm as it is carried downstream to a nearby female. This sperm enters the female pocketbook and fertilizes its eggs. Continuing to the right, the female mussel is shown displaying its lure in the shape of a blue fish to attract the blue gill fish host. The bluegill is attracted to the lure and the female is depicted releasing its glochidia larvae to attach to the gills of the bluegill. The bluegill continues swimming upstream to the right until a larval pocketbook is shown dropping off its bluegill fish host to burrow into the sediment and develop into an adult.

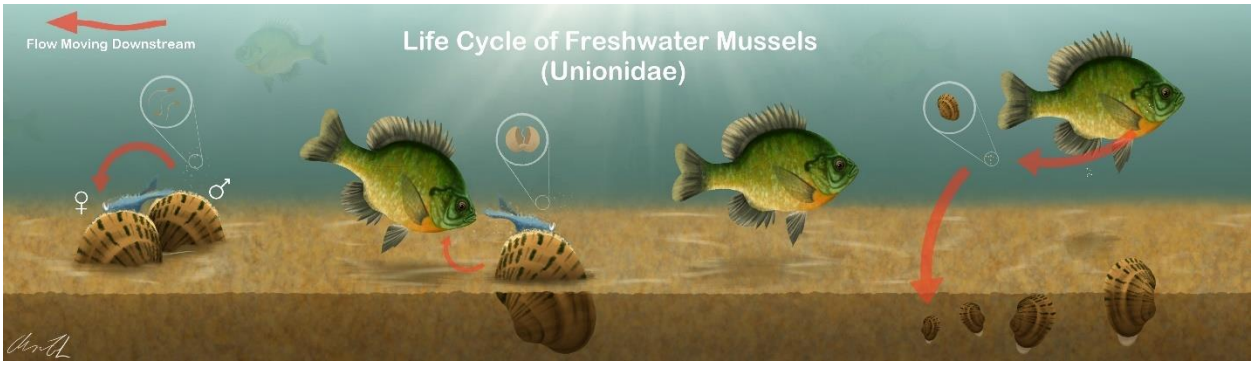


Figure 28. Mural of unionid life history and reproductive strategy that requires a fish hosts. The mussel species depicted is the plain pocketbook (Lampsilis cardium) with a bluegill (Lepomis macrochirus) as its fish host. The diagram will be used in a virtual gallery to help draw viewers in to learn about unionids and the volunteer program. A larger image can be found here: https://www.artbyaskari.com/science.

5. Discussion

The main purposes of the volunteer mussel surveys are a) to assess the status of unionid mussels in the Huron River Watershed, b) to provide data to inform other HRWC projects, and c) to educate and engage volunteers with freshwater mussels to promote awareness for a lesser appreciated and declining group of animals.

5.1 Role of mussel surveys

HRWC's mussel monitoring program will be one of the first major organized programs in Michigan specifically for volunteer mussel surveys. Most mussel surveys in Michigan have been conducted by mussel experts from research, government, and consulting groups such as Central Michigan University, MDOT, ASTI Environmental, EGLE, MDNR, and MNFI. This may largely be due to permitting restrictions and the lack of awareness about unionids. This monitoring program will make it possible for volunteers from around the Huron River Watershed to participate in mussel surveys and contribute to meaningful conservation efforts.

The species diversity and abundance results from the mussel surveys will help to evaluate the status of mussels in the Huron River Watershed. Since mussels are water quality indicators, the presence of mussels can indicate that a stream has sufficient dissolved oxygen levels, low levels of pollutants and turbidity, stable substrates and stream hydrology, and healthy populations of host fishes (Badra, 2020). Generally, streams that have at least four species of unionids present can be considered to host diverse mussel communities (Hanshue et al., 2021). Conversely, the absence of mussels does not necessarily indicate that a habitat is not favorable, as there could be a variety of factors including an insufficient population of host fish, the

presence of toxins, low availability of dissolved oxygen, or even just that unionids are naturally missing (Rathbun, 2022). Therefore, the presence of mussels can indicate if a stream has healthy favorable conditions, however, the absence of mussels does not entirely exclude a stream as suitable habitat (Rathbun, 2022).

Information from the surveys on where mussels are located throughout the Huron River Watershed will help guide HRWC as to which sites might be higher priority for protection and restoration measures. High quality sites with healthy, diverse communities of mussels can be marked for protection, especially for sites with state and federally listed species. These high-quality sites should also be monitored to protect them from the spread of zebra mussels, quagga mussels, and Asian clams. In sites where new occurrences of state or federally listed species are recorded, stronger protections can be obtained for those streams. In these instances, after finding a federally listed species in Group 1 and 2 streams where they are not expected to be found, the survey should be stopped to contact USFWS for guidance at the Michigan Field Office in Lansing at (517) 351-2555. Additionally, high quality sites that are identified through this survey program could potentially have their mussel populations augmented or re-introduced. One source will be a Michigan mussel hatchery being built by Central Michigan University and the MDNR (Central Michigan University Communications, 2020).

Surveys will also help to find mussels affected by construction activities to relocate them to protected sites. This type of relocation is currently required for state and federally listed species and recommended for non-listed species (Hanshue et al., 2021). These activities also provide opportunities for volunteer monitoring to assess how populations fare after relocation.

Sites that have mussels observed in habitats facing any threats can be prioritized for restoration. Sites with sparse mussel communities in streams with turbid water could be optimal

locations to implement rain gardens, riparian buffers, and other forms or green infrastructure to lessen excessive sediment inputs. Streams that have mussels present but hold low populations of host fish or have low connectivity to the rest of the watershed may require measures to protect or restore host fish populations or to reconnect pathways to the watershed. Improving the access of mussels to host fish may contribute to rationale that supports the removal of old dams and the replacement or improvement of ineffective culverts.

5.2 Similar programs

Several organizations across the United States have volunteer programs for mussel monitoring. These programs vary in levels of volunteer involvement.

The Anacostia Watershed Society (AWS) has a freshwater mussel survey program for the Anacostia River Watershed in Washington DC and Maryland. This program has involved around 120 volunteers that work under AWS staff to collect data during field surveys and to monitor floating baskets of mussel cultures propagated at the Harrison Lake National Fish Hatchery (J. Bogantes, personal communication, August 1, 2022). These surveys have helped AWS gauge the health of mussel communities over time by producing data about the distribution, growth, and survival of propagated and released mussels (J. Bogantes, personal communication, August 1, 2022).

Wisconsin has a mussel monitoring program that was developed by the Wisconsin Aquatic and Terrestrial Resources Inventory and sponsored by the Wisconsin Department of Natural Resources. This program conducts monitoring training for volunteers and has a project page on the online network iNaturalist for their volunteers to submit photos of mussels (Weinzinger & Kitchel, 2018). Unlike in Michigan, the collection of live mussels in Wisconsin

without a permit like the Collector's Permit is legal, so volunteers are free to conduct their own surveys (Weinzinger & Kitchel, 2018).

The Texas Mussel Watch of the Wildlife Diversity Program is similar to Wisconsin's program with the less supervised participation of volunteers. Fishing licenses and endorsements are required in Texas for residents to collect freshwater mussels and can be purchased with a yearly resident freshwater package for $30, a non-resident freshwater package for $58, or a senior freshwater package for residents 65 and older for $12 (Texas Parks and Wildlife Department, n.d.). The Texas Mussel Watch program encourages volunteers to search for mussels and submit photos to their iNaturalist page. By April 2023, over 1300 observations have been submitted to the Texas Mussel Watch iNaturalist page (Freshwater Mussels of Texas, 2012).

5.3 Social value of mussel citizen science program

The proposed mussel surveys will have high social value because of the volunteer engagement and education opportunities they will present. Volunteerism has proven to be a valuable tool in restoration because it can increase knowledge and awareness about ecology and environmental issues, improve community relationships with the environment, promote sustainable behaviors and lifestyles, and encourage social interaction between community members (Dresner et al., 2014; Stepenuck & Green, 2015). Freshwater mussel conservation depends heavily on the promotion of sustainable activities such as cleaning equipment to prevent the spread of zebra mussels, spreading awareness about the use of herbicides, advocating for the implementation of rain gardens and green infrastructure, and the overall practice of safe recreational behavior in Michigan waterways as to not disturb or harm native mussels.

5.4 Limitations and recommendations for future studies

5.4.1 Sites not included in recommendations

Although 85 total locations were identified as potential sites for the program, 31 of these sites were either not visited or not included in the recommendation process. Reasons for not visiting or choosing these sites included occasions when sites were not accessible, private access was required, or alternative sites nearby were chosen instead. Since 46 sites were recommended from the 54 that we visited that include numerous locations spanning across the various tributaries of the Huron River, inclusion of the remaining 31 sites were not deemed a priority for the time being. Information for those sites was made available for HRWC in case additional sites are needed going forward.

5.4.2 Limit of training surveys

Originally, I intended to conduct more surveys with Dr. Renee Mulcrone in the Summer and Fall of 2022. However, that was impractical due to unfavorable weather and scheduling complications. It would have been desirable to conduct additional surveys to involve more volunteers and get a better sense of how surveys would work with a larger group of volunteers than the three present in my surveys with Dr. Mulcrone to have more information to provide in this study from that experience. I plan to help implement and refine the program design details and materials in future mussel surveys with HRWC staff and volunteers during the summer of 2023. This will provide guidance on how effective the mussel survey procedures and protocols work with volunteers that represent a range of experience in aquatic surveying and unionid species identification.

5.4.3 Species not included in the set of 3D models

Since the set of 3D models was produced as an experimental phase for HRWC, using specimens from the University of Michigan Museum of Zoology at no cost by CultureVerse, not every species present in the Huron River was scanned and printed. I decided to select the 16 unlisted species of the Huron River because the scanning and printing process takes considerable time and the museum mussel specimens were loaned on a limited time basis. In Group 1 streams, surveys can be conducted by a leader with only a Collector's permit with some experience with species identification. Since state or federally threatened species are not likely to be in Group 1 streams, I deemed it would be more valuable to produce 3D models of the unlisted species to help with species identification, in particular when identification experts are not present. In Group 3 streams, a mussel expert would be present so having the 3D models would not be as necessary for help in identifying federally or state T/E species. CultureVerse volunteered to produce 20 to 30 prints for this project and that can be extended as the program develops.

5.5 Future developments and applications

5.5.1 Implementing the program design

After the development of this program design, I will help to conduct mussel surveys in the Huron River Watershed in the summer of 2023 with HRWC staff and volunteers. These surveys will provide an opportunity to implement and refine the survey protocol. Further details for the sites and dates for survey events will be decided upon with HRWC going forward. This program will also help to serve as an example for other watershed groups to adopt their own mussel monitoring programs in the future.

5.5.2 Virtual gallery development

The virtual gallery developed through collaboration with CultureVerse will display the mussel scans, species identification descriptions, general mussel information, and information about the monitoring program. CultureVerse and its partner organization Saganworks have produced virtual galleries to display a variety of art and image-based products, including a virtual exhibit made for the University of Michigan Museum of Natural History that displays a 3D collection of whale fossils to tell a story of evolution (Museum of Natural History, n.d.).

The virtual gallery developed for the HRWC's mussel program will tell a story of unionids, the threats they face, current conservation efforts, and the survey program design with information provided on how to identify species using the scanned mussel models. My digital painting of the mussel reproductive cycle is part of the gallery as another form of scientific engagement through art. The gallery will also have an augmented-reality mechanism for users to display the mussel models using a smartphone camera. Through the gallery, I hope to educate people about unionids and provide another opportunity to get volunteers interested in participating in the program.

5.5.3 Outreach and collaboration with other programs

Opportunities may also arise to collaborate with other programs and mussel experts across the state. Joseph Rathbun has helped to lead mussel identification workshops and has offered to conduct a workshop for HRWC's volunteers. This would be a good opportunity to introduce the program to the local community and to gauge interest in future volunteer mussel surveys.

Once the program is fully developed, it also may be valuable to reach out to other watershed groups throughout Michigan such as the Clinton River Watershed Council, the Flint River Watershed Coalition, Friends of the Rouge, and Friends of the St. Clair River to share program materials to help them develop mussel programs for their own rivers. By expanding volunteer mussel monitoring efforts beyond the Huron River watershed, mussel populations across the state can be assessed and protected further than by government, contract, and research efforts. It could also be beneficial to create a Michigan iNaturalist page for mussels like those in the Texas and Wisconsin mussel programs to collaborate with volunteers across Michigan in submitting mussel observations.

6. Conclusion

Innovative solutions that expand beyond what academic and governmental approaches can handle are especially critical to the success of conservation in the face of anthropogenic threats that have increasingly degraded natural habitats. Volunteerism and citizen science are posed as valuable opportunities to involve local communities in meaningful conservation. This project extended across various fields of ecology, the arts, and social contexts to create an initiative that will help protect Michigan's native freshwater mussels and contribute to improving the overall wellbeing of the Huron River Watershed. Future improvements, as the program is conducted, may provide an example to other watershed coalitions in Michigan to adopt their own mussel survey programs. This project helps suggest the potential opportunities that are available through collaborations across fields to improve the impact of conservation programs, especially for the more underappreciated animals like unionids.

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Zanatta, D., & Woolnough, D. (2011). Confirmation of Obovaria olivaria, Hickorynut Mussel (Bivalvia: Unionidae), in the Mississagi River, Ontario, Canada. *Northeastern Naturalist*, *18*(1), 1-6. https://doi.org/10.1656/045.018.0101

Appendix A. Mussel Species of the Huron River Watershed. If "status" is blank, the species is not listed.

Species Name	Common Name	MI Status	US Status
Actinonaias ligamentina	Mucket		
Alasmidonta marginata	Elktoe	Special Concern	
Alasmidonta viridis	Slippershell	Threatened	
Amblema plicata	Threeridge		
Anodontoides ferussacianus	Cylindrical papershell		
Cyclonaias pustulosa	Pimpleback		
Cyclonaias tuberculata	Purple wartyback	Threatened	
Elliptio dilatata	Spike		
Epioblasma torulosa rangiana	Northern riffleshell	Endangered	Endangered (1993)
Epioblasma triquetra	Snuffbox	Endangered	Endangered (2012)
Fusconaia flava	Wabash pigtoe		
Lampsilis cardium	Plain pocketbook		
Lampsilis fasciola	Wavy-rayed lampmussel	Threatened	
Lampsilis siliquoidea	Fatmucket		
Lasmigona complanata	White heelsplitter		
Lasmigona compressa	Creek heelsplitter		

Lasmigona costata	Fluted-shell		
Leptodea fragilis	Fragile papershell		
Ligumia nasuta	Eastern pondmussel	Endangered	
Ligumia recta	Black sandshell	Endangered	
Obliquaria reflexa	Three-horned wartyback	Endangered	
Obovaria olivaria	Hickorynut	Endangered	
Obovaria subrotunda	Round hickorynut	Endangered	Proposed Threatened (2020)
Pleurobema sintoxia	Round pigtoe	Special Concern	
Potamilus alatus	Pink heelsplitter		
Ptychobranchus fasciolaris	Kidney-shell	Special Concern	
Pyganodon grandis	Giant floater		
Quadrula quadrula	Mapleleaf		
Strophitus undulatus	Creeper		
Toxolasma parvum	Lilliput	Endangered	
Truncilla truncata	Deertoe	Special Concern	
Utterbackia imbecillis	Paper pondshell	Special Concern	
Villosa fabalis	Rayed bean	Endangered	Endangered 2012
Villosa iris	Rainbow	Special Concern	

Appendix B. Michigan Fisheries Cultural & Scientific Collector's Permit Application Process

1. Go to the link: https://www.michigan.gov/dnr/managing-resources/fisheries/cultural-scientific-collectors-permit-fisheries
2. Under **New online application**, select the Scientific Collector's Permit Application link. This will transport you to a survey to fill out the permit application.
3. For **Permit Activity Type** select the first option: "Scientific Collector's Permit to survey, handle, collect or possess Fish, Amphibians, Reptiles, Crustaceans or Mollusks"
4. For **Permit Type** select "Scientific Investigation – Non-Consulting or Partner Agency Related"
5. Select a preferred Title and write the Applicant First and Last Name
6. For **Institution/Affiliation Name** write: "Huron River Watershed Council"
7. Write the applicant's mailing address, phone number, and email address where the approved permit can be delivered to
8. For **Supervising Professor/Teacher (if applicable)** leave blank
9. Co-applicants if multiple volunteers are getting permit at the same time. Their names must also be listed in the Study Plan box along with the reason they are also being listed on the permit.
10. For **Study Plan** write a summary of HRWC mussel surveys, along the lines of:

    "I am applying for a permit to be able to participate in and lead mussel surveys with the Huron River Watershed Council's volunteer mussel monitoring program. In these surveys mussel specimens will be collected for identification then returned to their collection spot. We will not be using any lethal methods or removing specimens off

site." (If known, insert plans and dates with the number of sites or frequency of surveys that are currently planned by HRWC).

11. For **Specimen Types** select: "Mollusks"
12. Under the following activities included in study plan, select "NO"
13. For **Common and Scientific Name(s) of Species** select the following non T/E species: Creek heelsplitter (*Lasmigona compressa*), Cylindrical papershell (*Anodontoides ferussacianus*), Deertoe (*Truncilla tru*ncata), Elktoe (*Alasmidonta marginata*), Fat mucket (*Lampsilis siliquoidea*), Floater (*Pyganodon grandis*), Fluted-shell (*Lasmigona costata*), Fragile papershell (*Leptodea fragilis*), Kidneyshell (*Ptychobranchus fasciolaris*), Mapleleaf (*Quadrula quadrula*), Mucket (*Actinonaias ligamentina*), Paper pondshell (*Utterbackia imbecillis*), Pimpleback (*Quadrula pustulosa*), Pink heelsplitter (Po*tamilus alatus*), Pocketbook (*Lampsilis cardium*), Rainbow (*Villosa iris*), Round pigtoe (*Pleurobema sintoxia*), Spike (*Elliptio dilatata*), Strange floater (*Strophitus undulatus*), Three-ridge (*Amblema plicata*), Wabash pigtoe (*Fusconaia flava*), White heelsplitter (*Lasmigona complanata*)
14. For **Survey/Collection Methods** submit the following:
    a. Planned survey procedures:
        i. Note site habitat information including temperature, water flow speed, water depth, substrate type, and GPS location and take photos of the site.
        ii. Start a timer when the survey starts to record how long the survey lasted to gauge surveying effort.
        iii. Collect live mussels and dead shell material by hand using glass-bottom viewing buckets to search.

iv. Spread volunteers out in the stream to get samples across the site and prevent any rocks or sediment from getting kicked downstream into another volunteer. Surveyors should stay in shallow areas to ensure safety.

v. Take photos of live and dead specimens and identify, count, and record species using field guides, 3D models, and survey leader knowledge.

vi. When returning mussels to the stream after collection and identification, place them flat to allow them to reorient themselves and not suffocate the mussels.

vii. Properly clean all equipment after the survey event has concluded.

15. For Location information, select:

    Counties: "Oakland, Livingston, Ingham, Jackson, Washtenaw, Wayne, and Monroe"

    Site Name or Description: "Huron River Watershed"; if surveys are already planned list the specific sites

    Location picker: Place a point along the Huron River in Ann Arbor (e.g., by Barton Park); or any specific sites if surveys are already planned

16. Sign applicants' signature and the date

17. Submit application

Appendix C. Michigan Threatened/Endangered Species Permit Application

(PDF can be accessed at https://www.michigan.gov/dnr/managing-resources/wildlife/wildlife-permits/threatened-endangered-species)

INSTRUCTIONS: Please type or print all information except the signature and mail with attachments to the Wildlife Division. Federal permits may be required for federally listed or migratory species. A proposal letter is required for any new or amended proposals. Instructions for proposals are on the back of this application.

APPLICANT INFORMATION

- Select New Permit
- Select Education or Scientific
- Put Huron River Watershed Council for Organization Name

SPECIES INFORMATION (PROPOSAL LETTER REQUIRED FOR NEW APPLICANTS)

Species (Scientific or common names)

Slippershell, Purple wartyback, Eastern pondmussel, Black sandshell, Three-horned wartyback, Hickorynut, Lilliput

Location (Be specific. Include Michigan county(ies))

Huron River Watershed, Washtenaw County, Wayne County, Oakland County, Livingston County

Time period requested (usually one to three years)

Number of plants and/or animals to be handled, collected, relocated, etc.

Specimens will be surveyed and counted on site

Name and location of public institution where authorized specimens will be placed

Huron River Watershed Council, 117 N 1st St Ste 100, Ann Arbor, MI 48104

Appendix D. HRWC Mussel Survey Report Form

Date:	Site and Stream Name:	GPS Coordinates:
Survey Leaders:		

Site Information:

Stream Max Depth:	Water Flow Speed:	Water Temperature:	Substrate Type:
% Flowering Plants:	% Fruiting Plants:	6 plant species present:	

Survey Results:

Species	**# of Alive Adults**	**# of Alive Juveniles**	**# of Dead Shells**	**Notes**

Additional notes (evidence of mussel lure display, site observations, weather occurrences, site quality, threats to site, etc.):

Appendix E. Site Selection Information

Criteria Abbreviations:

- **Site P** = Site Priorities (1 Primary recommended sites, 2 Secondary recommended sites, 0. Site not recommended).
- **G#** = Stream Group Number (1: Collector's Permit, 2: State Permit. 3: Federal Permit)
- **Accessibility**: (Parking = P, Walking = W, and Sampling = S); were ranked by E (easy), M (moderate), and H (hard)
- **Owner**: HCMA = Huron Clinton Metropark Authority, UMich = University of Michigan

Site P	Stream Name	G#	Owner	GPS	P	W	S	D	Substrate
2	Huron River at Huron Meadows 1	3	HCMA	42°28'42.2"N 83°46'05.0"W	H	E	M	3	sand, rock
0	Huron River at Huron Meadows 2	3	HCMA	42°28'23.7"N 83°46'49.9"W	E	H	H	2	very deep mud
1	Huron River at Huron Meadows 3	3	HCMA	42°28'26.8"N 83°46'59.4"W	E	E	E	2	sand, gravel
2	Huron Meadows 4	3	HCMA	42°28'28.5"N 83°47'11.8"W	E	E	E	3	sand, gravel
1	Huron River at Hudson Mills 1	3	HCMA	42°23'09.6"N 83°54'44.0"W	E	E	E	3	large rocks, gravel
1	Huron River at Hudson Mills 2	3	HCMA	42°23'00.4"N 83°54'53.8"W	E	E	M	1	rock
1	Huron River at Hudson Mills 3	3	HCMA	42°22'57.3"N 83°54'59.2"W	E	E	E	3	silt, rock

1	Huron River at Hudson Mills 4	3	HCMA	42°22'45.5"N 83°55'03.9"W	E	M	E	1	gravel
1	Huron River at Hudson Mills 5	3	HCMA	42°22'39.8"N 83°55'00.3"W	E	M	E	2	sand, mud
1	Huron River at Hudson Mills 6	3	HCMA	42°22'32.2"N 83°54'59.6"W	E	M	E	2	silt, gravel
2	Huron River at Hudson Mills 8	3	HCMA	42°22'09.9"N 83°54'28.3"W	E	H	E	2	firm sand, silt, gravel
1	Huron River at Dexter-Huron 1	3	HCMA	42°19'48.0"N 83°51'44.8"W	E	E	E	2	firm sand, gravel
1	Huron River at Dexter-Huron 2	3	HCMA	42°19'44.7"N 83°51'41.0"W	E	E	E	2	firm sand, gravel
1	Huron River at Dexter-Huron 3	3	HCMA	42°19'40.3"N 83°51'32.2"W	E	E	E	2	firm sand, gravel
2	Huron River at Willow Metropark	3	HCMA	42°07'36.0"N 83°21'36.0"W	E	M	M	2	gravel, sand, mud
1	Huron River at Delhi Metropark 1	3	HCMA	42°19'59.6"N 83°48'28.8"W	E	M	H	3	rock, gravel, sand
2	Huron River at Delhi Metropark 2	3	HCMA	42°19'57" N, 83°49'01" W	E	E	E	2	rock, gravel, sand

2	Huron River at Delhi Metropark 3	3	HCMA	42°20'01.0"N 83°48'38.0"W	E	E	E	2	rock, gravel, sand
1	Portage River at Hiland Lake Dam	1	Mixed	42°26'02.5"N 83°59'20.7"W	E	M	E	2	rock, gravel
0	Portage River at Hiland Lake	1	Park	42°25'33"N 84°00'04"W	H	M	H	3	sand, deep mud
2	Portage River at Unadilla Rd	1	Public	42°25'50.2"N 84°03'28.3"W	E	E	E	3	sand, mud
1	Woodruff Creek at Ford Rd	2	Public	42°31'10.8"N 83°43'15.2"W	M	M	E	2	sand, gravel, rocks
1	Woodruff Creek at Strawberry Lake Rd	2	Public	42°25'39.0"N 83°52'57.0"W	E	E	E	2	sand, gravel
0	Honey Creek at Cedar Lake Rd	2	Public	42°27'30"N 83°57'57"W	M	E	M	3	mud
1	Honey Creek at Mill Pond	2	Private	42°27'14.5"N 83°56'49.2"W	E	E	E	2	gravel
2	Portage River at Williamsville Rd	2	Private	42°26'18"N 84°05'56"W	M	E	E	3	sand, sediment

2	Huron River at Hamburg Rd	3	Private	42°27'54.7"N 83°48'00.4"W	E	E	E	2	rock, gravel
1	Huron River at Highland Rd	1	Public	42°39'27"N 83°27'26"W	E	M	H	3	sand, mud
2	Huron River at Oxbow Lake Rd	1	Private	42°37'07"N 83°29'24"W	M	M	H	2	mud, silt
0	Norton Creek at E Buno Rd	1	Public	42°33'09"N 83°33'44"W	E	E	H	4	mud
1	Pettibone Creek at E Livingston Rd	1	Park	42°38'18.0"N 83°54'24.0"W	E	E	E	2	sand, mud
2	Huron River at Proud Lake	2	Park	42°34'23.0"N 83°32'30.0"W	E	H	E	3	sand, rock
1	Huron River at Wixom Rd	2	Park	42°34'26.6"N 83°33'32.3"W	E	E	E	2	sand, rock
1	Huron River at W Dawson Rd	2	Park	42°33'54.0"N 83°37'37.2"W	E	E	E	3	sand, gravel, rocks
1	Huron River at Island Park	3	Park	42°17'27.9"N 83°43'42.3"W	E	E	E	2	rock, sand, gravel
1	Huron River at Riverside Park Ann Arbor	3	Park	42°14'40.2"N 83°36'39.6"W	E	E	E	2	rock, sand, gravel

2	Huron River at Barton Darm	3	Park	42°18'27.1"N 83°45'19.4"W	E	E	M	2	mud
1	Huron River at Riverside Park Yspilanti	3	Park	42°14'40.2"N 83°36'39.6"W	E	E	E	2	gravel, firm sand
1	Huron River at Nichols Arboretum	3	UMich	42°16'58" N, 83°43'14"W	E	E	E	2	gravel, sand
1	Huron River at Bell Rd	3	Public	42°24'04" N, 83°54'30" W	E	E	E	2	gravel
1	Honey Creek at Wagner Rd	2	Public	42°19'02.3"N , 83°47'46.7"W	M	E	E	2	rock, sand
1	Honey Creek at Jackson Rd 1	2	Public	42°17'16.4"N 83°49'34.7"W	E	E	E	2	rock, sand
0	Honey Creek at Jackson Rd 2	2	Public	42°17'21"N 83°50'07"W	E	H	M	2	large rocks, mud
0	Honey Creek at W Liberty Rd	2	Park	42°16'15"N 83°51'16"W	M	H	E	1	rock, sand, mud
1	Fleming Creek at UM Botanical Gardens	2	UMich	42°16'23.9"N 83°39'50.4"W	E	E	E	2	rock, gravel

1	Fleming Creek at Parker Mill County Park	2	Park	42°18'00.0"N 83°39'35.3"W	E	E	E	2	rock, gravel
1	Fleming Creek at Warren Rd	2	Public	42°19'53.4"N 83°39'45.7"W	E	E	E	3	rock, gravel
1	Mill Creek at Mill Creek Park	2	Park	42°20'21.8"N 83°53'24.7"W	E	E	M	3	rock, gravel, sand
0	Mill Creek at Jackson Rd	2	Private	42°17'24.0"N 83°54'26.3"W	H	E	M	3	sand and rock
0	Mill Creek at N Fletcher Rd	2	Private	42°19'18.1"N 83°58'41.2"W	E	E	H	2	deep mud
2	Mill Creek at Klinger Rd	2	Public	42°15'45.7"N 84°00'14.0"W	E	W	H	4	sand, mud, gravel
2	Huron River at Huroc Park	1	Park	42°05'44"N 83°17'48"W	H	M	M	2	mud
1	Huron River at Flat Rock Boat Launch	1	Park	42°05'32"N 83°17'36"W	E	E	E	2	firm sand, gravel
2	Huron River at French Landing Park	3	Park	42°12'57" N, 83°26'24" W	E	E	E	2	mud

Appendix F. Michigan Threatened/Endangered Species Report Form

Michigan Department of Natural Resources-Wildlife Division
THREATENED/ENDANGERED SPECIES REPORT

BY THE AUTHORITY OF PART 365, ENDANGERED SPECIES PROTECTION, OF THE NATURAL RESOURCE AND ENVIRONMENTAL PROTECTION ACT,ACT 451 OF 1994, AND THE RULES ESTABLISHED THEREUNDER

Mail to: WILDLIFE DIVISION DEPARTMENT OF NATURAL RESOURCES PO BOX 30444 LANSING MICHIGAN 48909-7944	***INSTRUCTIONS:*** PLEASE PROVIDE ALL APPLICABLE INFORMATION IN THE REPORT, AND MAIL TO THE WILDLIFE DIVISION WITHIN 10 DAYS OF THE EXPIRATION DATE OF THE PERMIT OR BY DECEMBER 31, FOR EACH YEAR OF A MULTI-YEAR PERMIT.

PERMITTEE'S NAME (Last, First, Middle)	
NAME OF ORGANIZATION OR BUSINESS (if applicable)	
ADDRESS	
CITY, STATE, ZIP CODE	
TELEPHONE/EMAIL ADDRESS	PERMIT NUMBER

AS A HOLDER OF A THREATENED/ENDANGERED SPECIES PERMIT, YOU ARE REQUIRED TO COMPLETE THIS REPORT EVEN IF YOU DID NOT COLLECT, OBSERVE, OR RELOCATE ANY LISTED SPECIES. FAILURE TO REPORT MAY RESULT IN LOSS OF PERMIT RENEWAL. WHERE APPLICABLE, COPIES OF COMPLETE SPECIMEN LABELS OR REPORTS MAY BE SUBSTITUTED IN LIEU OF COMPLETING THIS FORM. HOWEVER, BE SURE TO PROVIDE THE INFORMATION ON THE FORM NOT INCLUDED ON THE LABEL OR IN THE REPORT. **COMPLETE ONE FORM FOR EACH SITE AND FOR EACH SPECIES AT A SITE.**

⑥ I did not collect, observe, or relocate any threatened or endangered species during the period covered by my permit. (sign and date form on reverse side).

⑥ I collected, observed, or relocated the species listed below.

SPECIES (Scientific and common names):

DATE OF OBSERVATION:

LOCATION (Legal description or UTM COORDINATES):
County: Town: Range: Section: ¼

DETAILED DIRECTIONS TO SITE: Include directions from nearest town or road. Draw or attach a map indicating the exact location of the observation, collection, and/or relocation site (**photocopies of USGS topographic maps preferred**).

OVER

POPULATION DATA:

Number of individuals: Observed: _____ Collected: _____ Captured/relocated: _____

Phenology (plants): % flowering: _____ % fruiting: _____ Apparent vigor:_____ Population age structure (animals): # adults: _____ # juveniles: _____ Evidence of reproduction:

RELOCATION DATA (if applicable):

Survival of relocated specimens: # relocated: _____ # surviving: _____ % surviving_____

HABITAT DATA:

Extent of habitat: (acres, sq. Meters, etc.): _____ % occupied by species: _____

Associated species. List 6 plant species in order of dominance, beginning with overstory if present:

Microhabitat description (soils, topography, etc.):

CONSERVATION DATA:

Overall site quality: Excellent: _____ Good: _____ Fair: _____ Poor: _____

Threats or need for protection (immediate? long-term?)

Other information needs (survey, monitoring, etc.):

INSTITUTION WHERE SPECIMENS DEPOSITED (If collected or salvaged):	Voucher/collection #:

COMMENTS, ADDITIONAL INFORMATION, RECOMMENDATIONS: (Attach sheets, reports, or photographs as appropriate):

SIGNATURE OF PERMITTEE	DATE

Appendix G. Huron River Species Descriptions

These species descriptions were adapted from “Field Guide to the freshwater mussels of Michigan” (Mulcrone & Rathbun, 2018). Photos were also taken from the field guide.

Species List

Huron River Unionid Species

Elktoe, *Alasmidonta marginata*

Slippershell, *Alasmidonta viridis*

Cylindrical papershell, *Anodontoides ferussacianus*

White heelsplitter, *Lasmigona complanata*

Creek heelsplitter, *Lasmigona compressa*

Fluted-shell, *Lasmigona costata*

Giant floater, *Pyganodon grandis*

Paper pondshell, *Utterbackia imbecillis*

Threeridge, *Amblema plicata*

Mucket, *Actinonaias ligamentina*

Northern riffleshell, *Eplioblasma torulosa rangiana*

Snuffbox, *Epioblasma triquetra*

Plain pocketbook, *Lampsilis cardium*

Wavy-rayed lampmussel, *Lampsilis fasciola*

Fat mucket, *Lampsilis siliquoidea*

Fragile papershell, *Leptodea fragilis*

Eastern pondmussel, *Ligumia nasuta*

Black sandshell, *Ligumia recta*

Threehorn wartyback, *Obliquaria reflexa*

Hickorynut *Obovaria olivaria*

Round hickorynut, *Obovaria subrotunda*

Pink heelsplitter, *Potamilus alatus*

Kidney-shell, *Ptychobranchus fasciolaris*

Liliput, *Toxolasma parvum*

Deertoe, *Truncilla truncata*

Rayed bean, *Villosa fabalis*

Rainbow, *Villosa iris*

Spike, *Eurynia dilatata*

Wabash pigtoe, *Fusconaia flava*

Round pigtoe, *Pleurobema sintoxia*

Pimpleback, *Quadrula pustulosa*

Purple wartyback, *Cyclonaias tuberculata*

Mapleleaf, *Quadrula quadrula*

Other Bivalve Species in Michigan

Pill/fingernail clams, Sphaeridae family (Native)

Zebra mussel, *Dreissena polymorpha* (Introduced)

Quagga mussel, *Dreissena bugensis* (Introduced)

Asian clams, *Corbicula* spp. (Introduced)

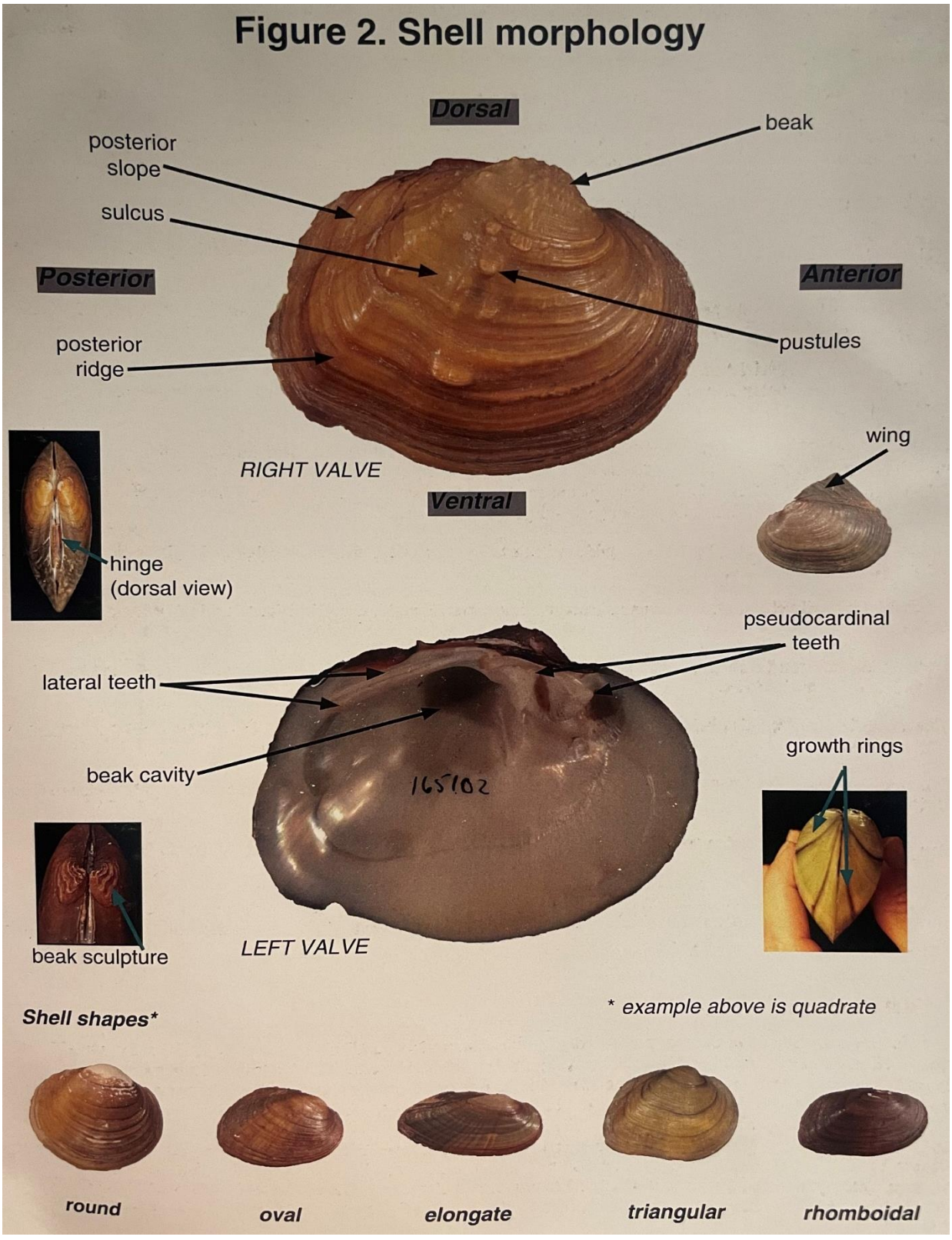
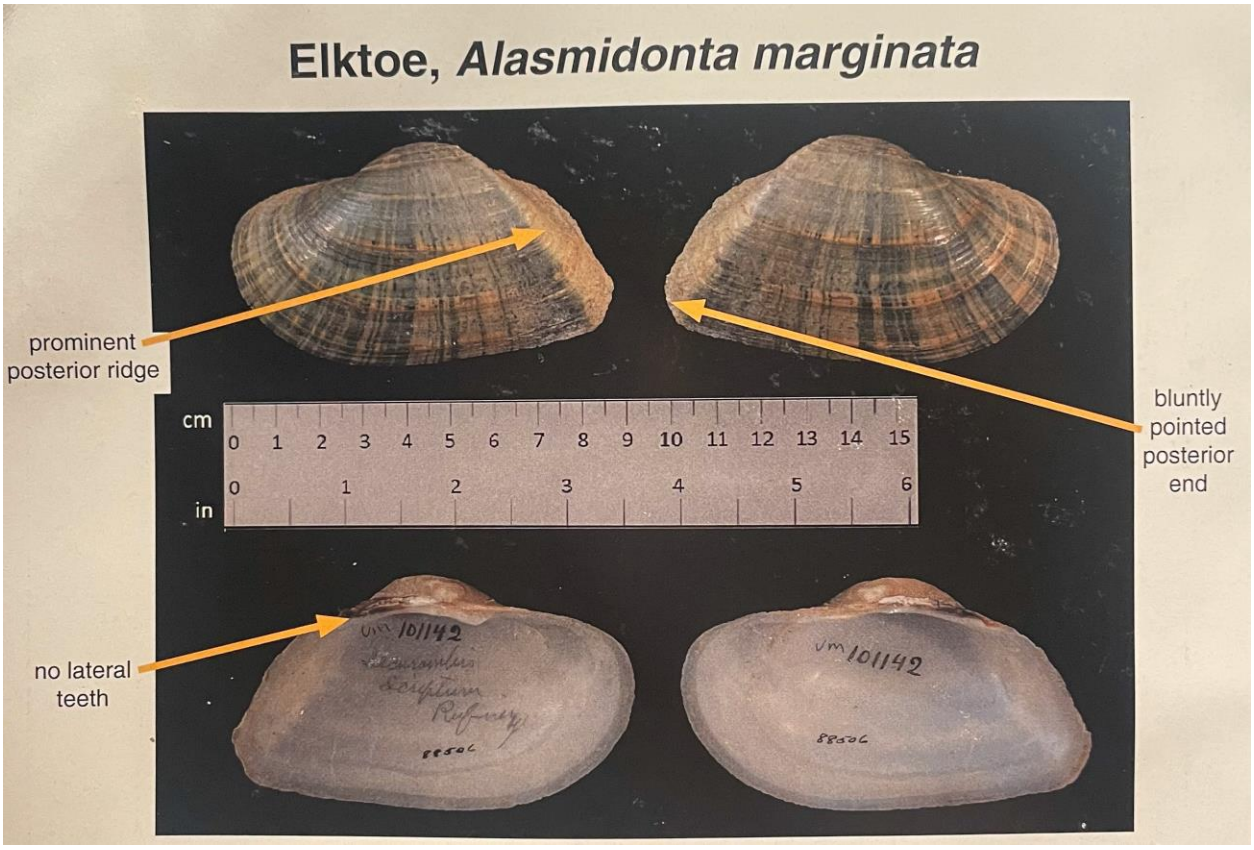


Figure 2. Shell morphology
Dorsal
beak
posterior slope
sulcus
Posterior
Anterior
pustules
posterior ridge
RIGHT VALVE
Ventral
wing
hinge (dorsal view)
pseudocardinal teeth
lateral teeth
beak cavity
growth rings
beak sculpture
LEFT VALVE
* example above is quadrate
Shell shapes*
round
oval
elongate
triangular
rhomboidal

Unionid Species



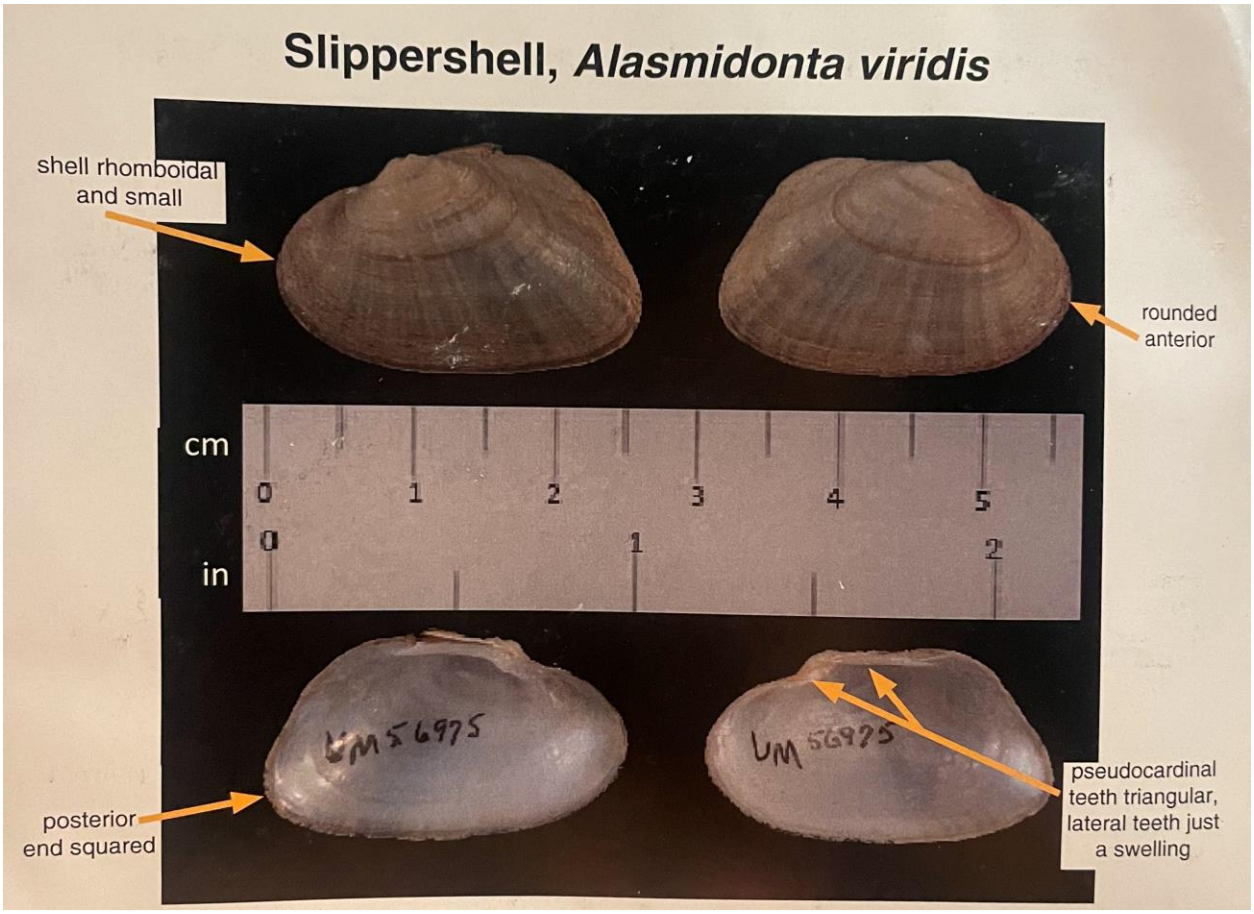
Elktoe, *Alasmidonta marginata* (Special Concern)

Size: up to 10 cm (4 in)

Shape: elongate and quadrate

Color: yellowish brown, lighter colored posterior end

Rays: broad green rays



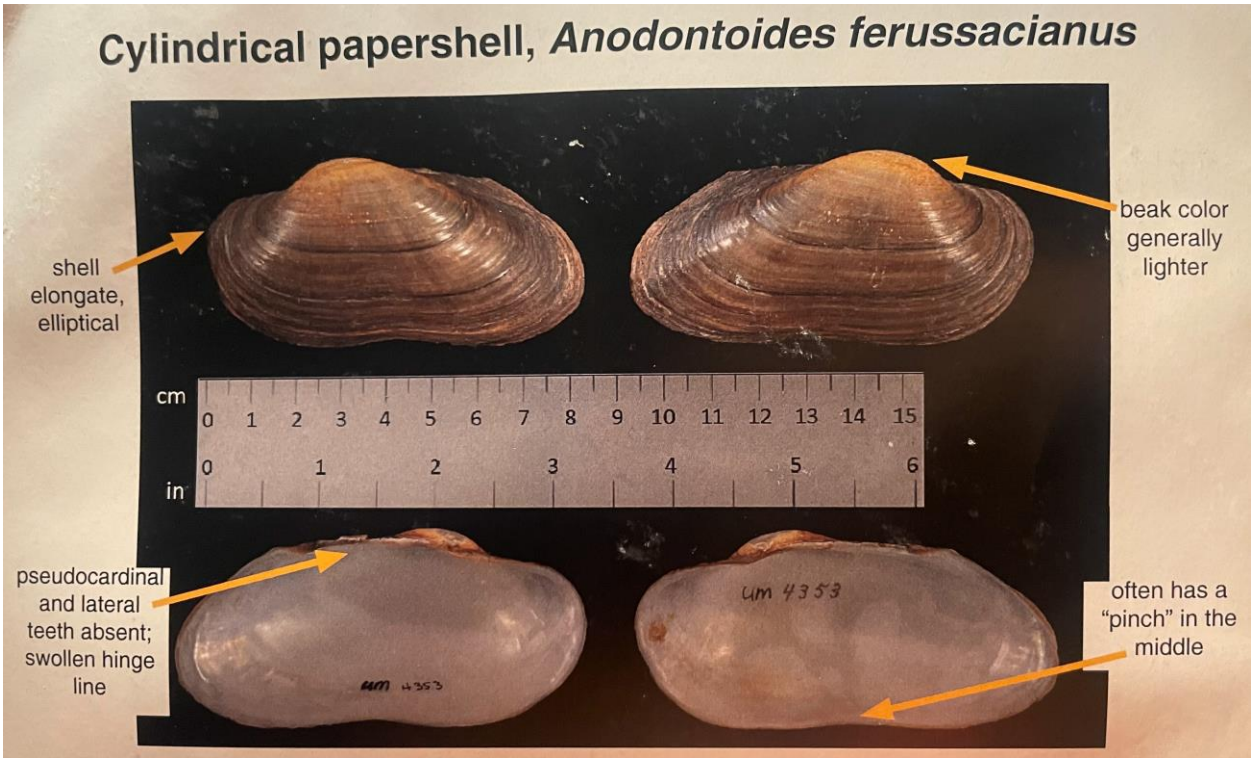
Slippershell, *Alasmidonta viridis* (Threatened)

Size: up to 4 cm (1.5 in)

Shape: rhomboidal

Color: yellowish green to yellowish brown

Rays: wavy green rays



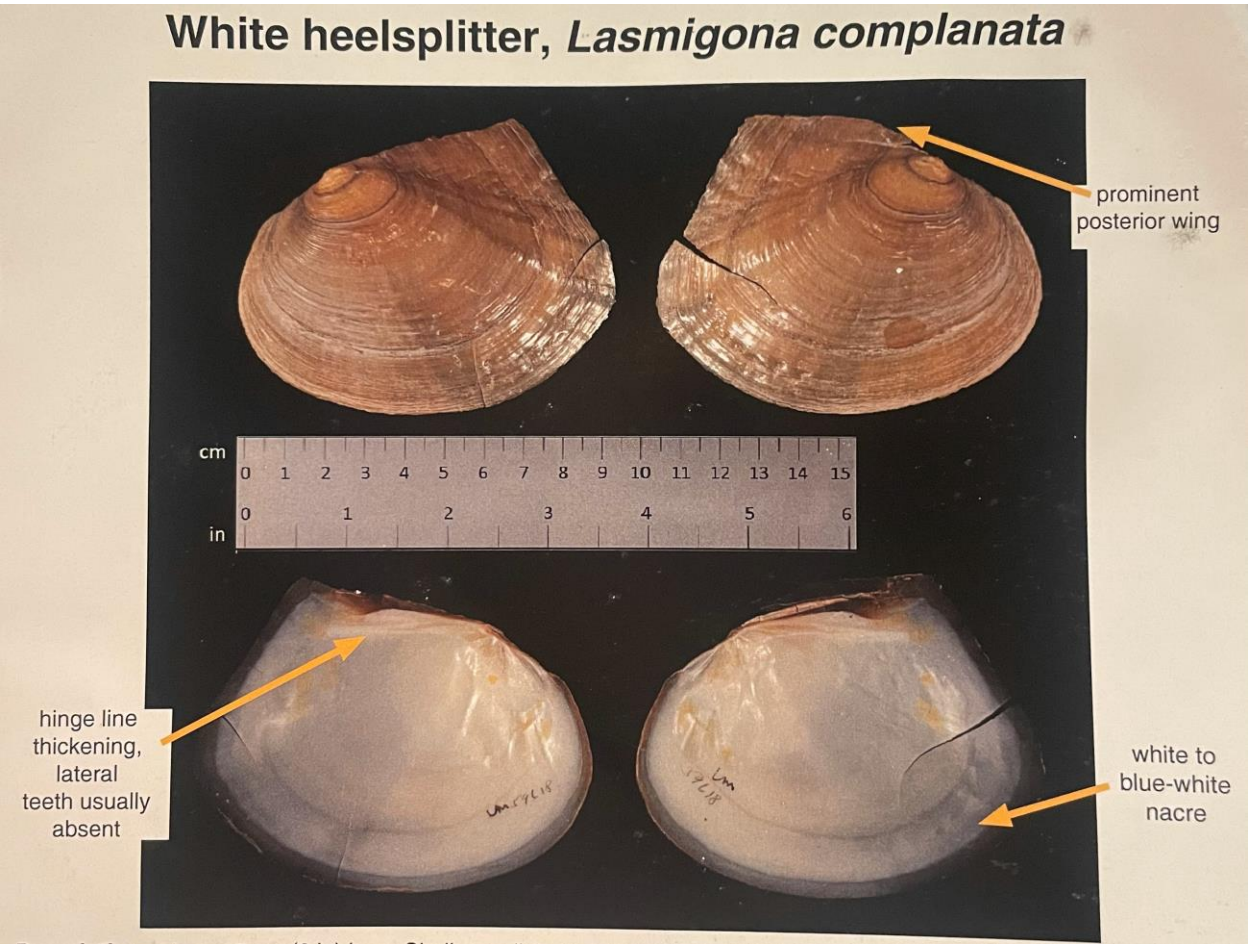
Cylindrical papershell, *Anodontoides ferussacianus*

Size: up to 7.5 cm (3 in)

Shape: elongate and elliptical; inflated with thin shell

Color: light green to yellowish brown, beak is lighter colored

Rays: sometimes has fine green rays



White heelsplitter, *Lasmigona complanata*

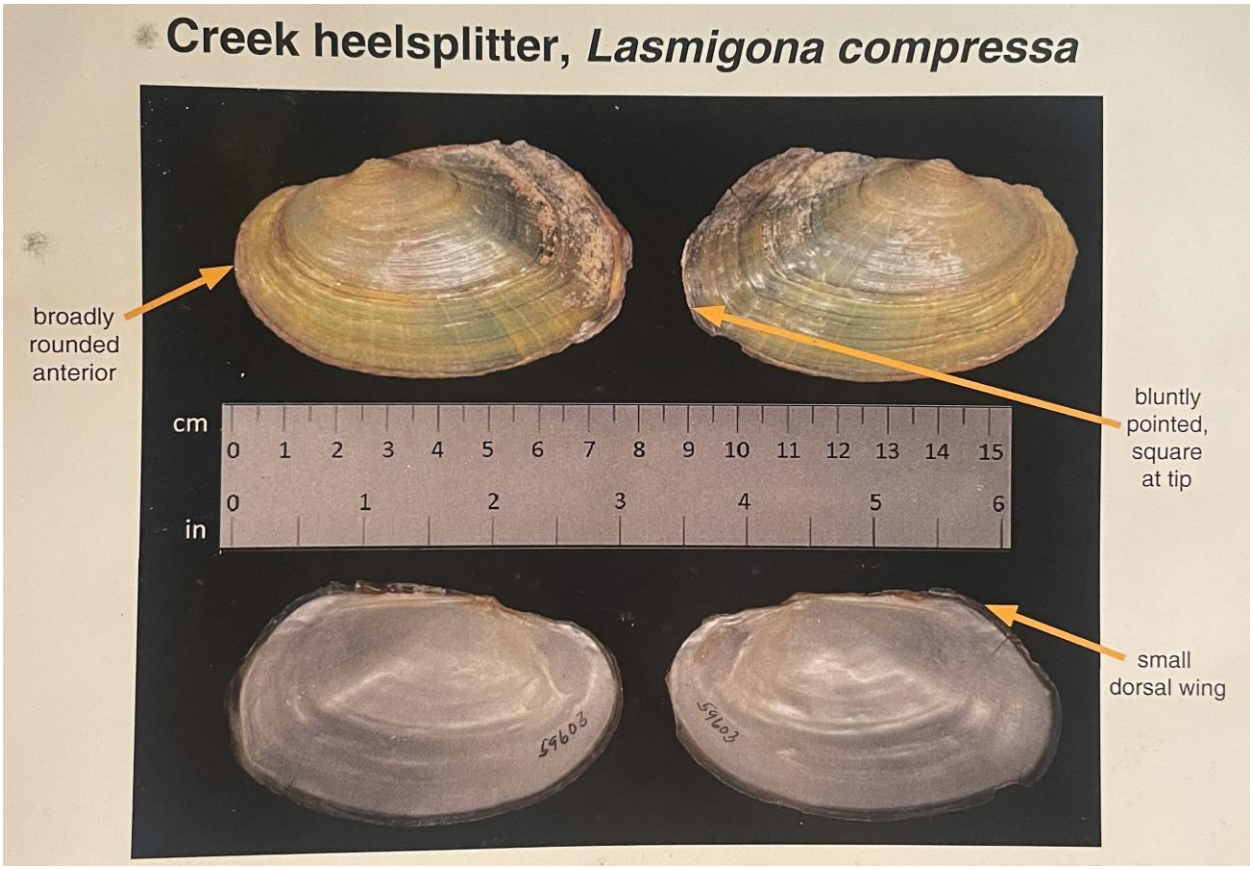
Size: up to 15 cm (6 in)

Shape: roundish oval to round; compressed with a low, flat beak

Color: tan brown

Rays: green and brown rays in young; dark brown to black rays in old

Additional features: prominent posterior wing and ridge



Creek heelsplitter, *Lasmigona compressa*

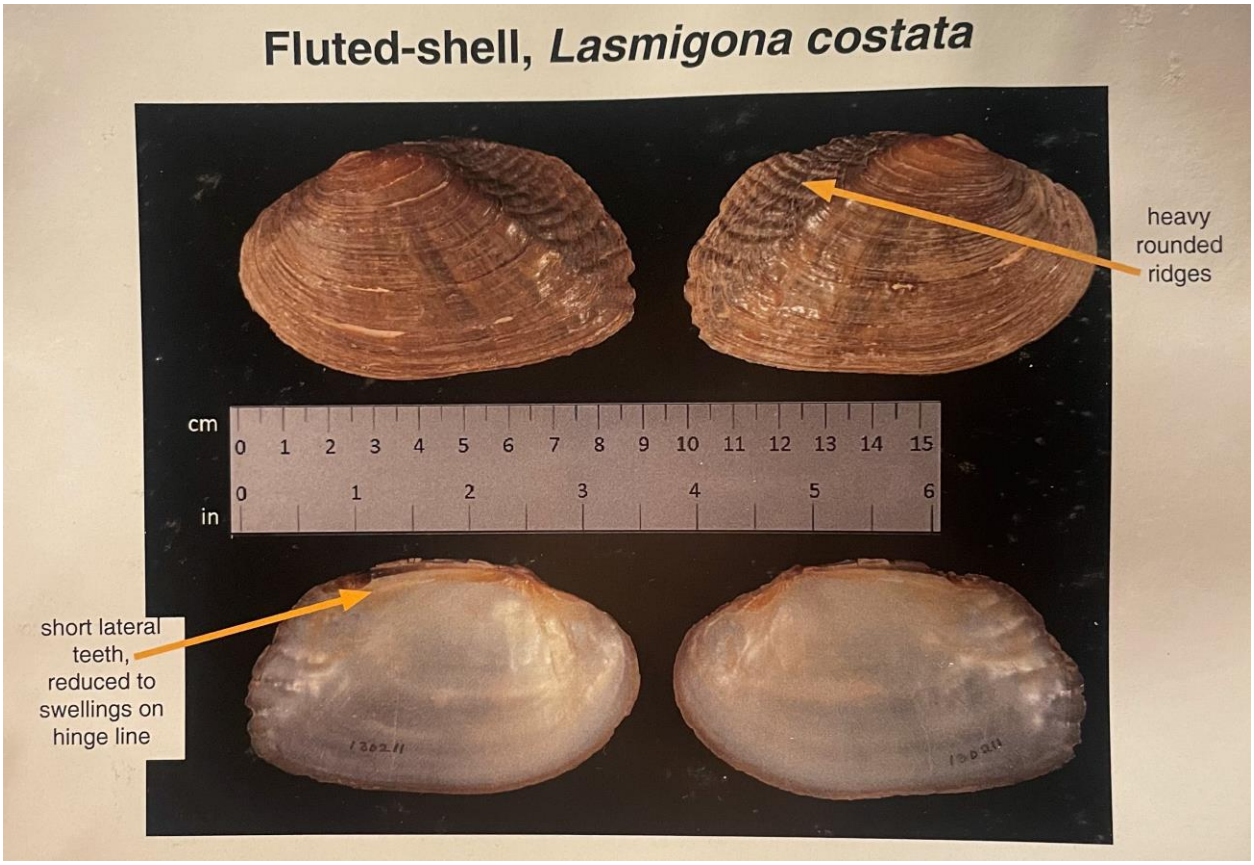
Size: up to 10 cm (4 in)

Shape: oval, elongate; thin and compressed

Color: yellow to yellowish green

Rays: numerous green rays in young; brown or green rays in old

Additional features: often has small dorsal wing



Fluted-shell*, Lasmigona costata*

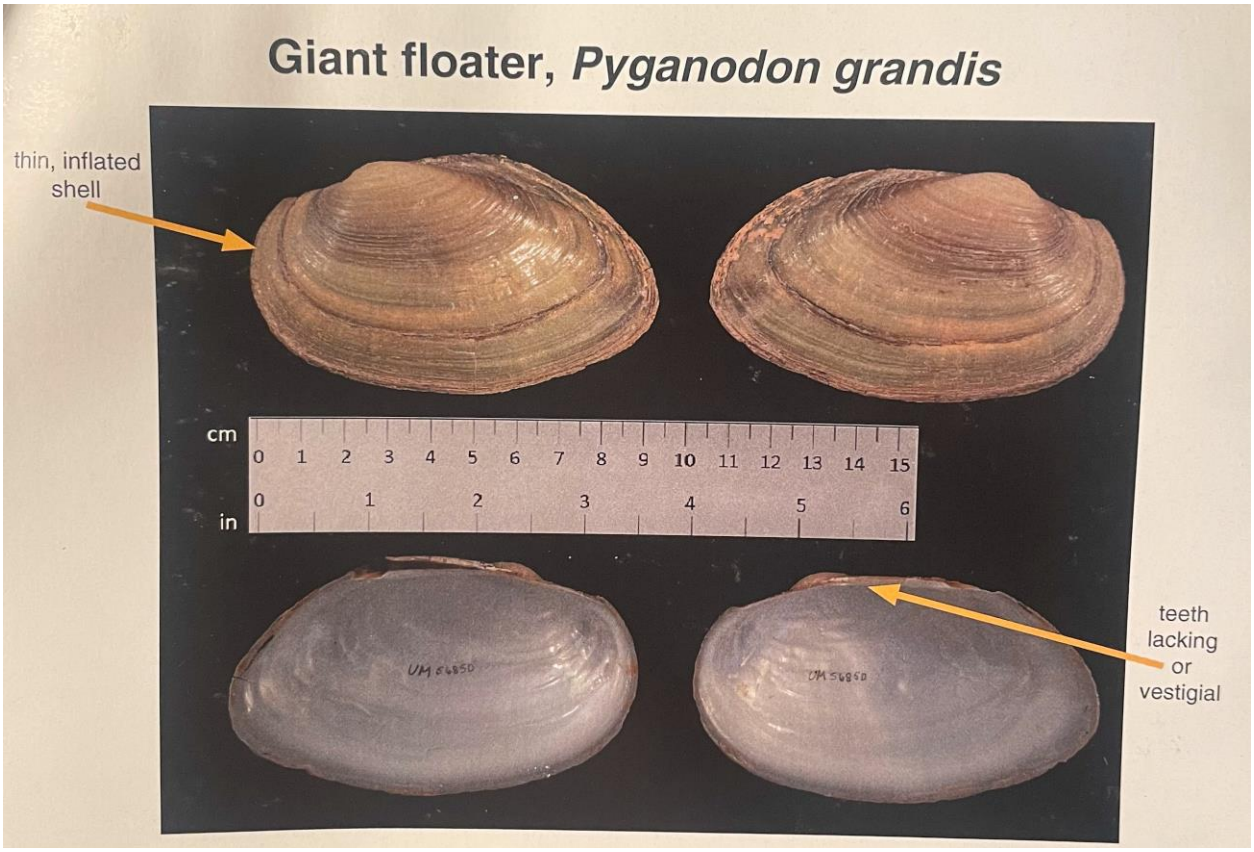
Size: up to 18 cm (7 in)

Shape: oval, elongate; compressed to moderately inflated

Color: brown

Rays: Green rays in young

Additional features: 10-20 heavy, round ridges on posterior slope



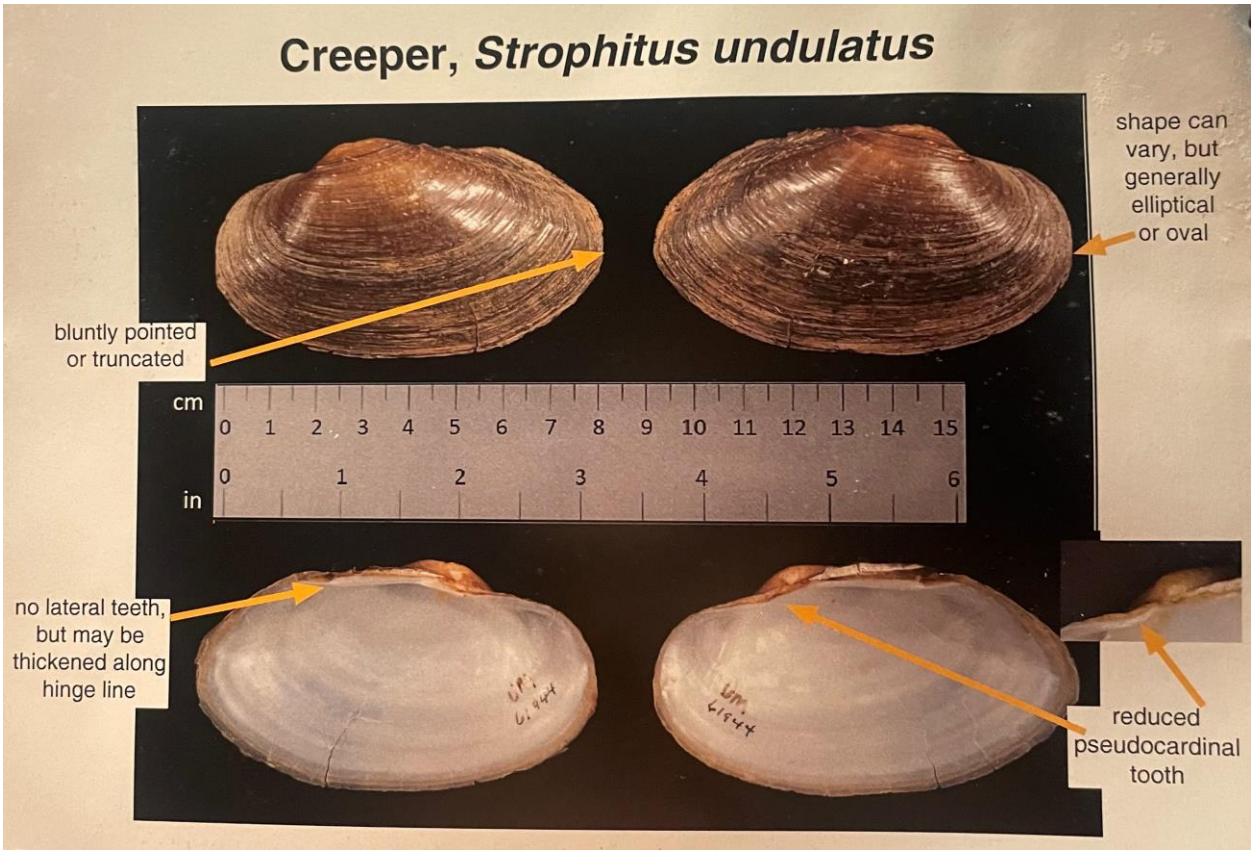
Giant floater, *Pyganodon grandis*

Size: up to 25 cm (10 in)

Shape: elliptical and elongate; thin, inflated shell; varies between individuals

Color: yellow to yellowish green

Rays: green rays in young, brown in old



Creeper/Strange floater, *Strophitus undulatus*

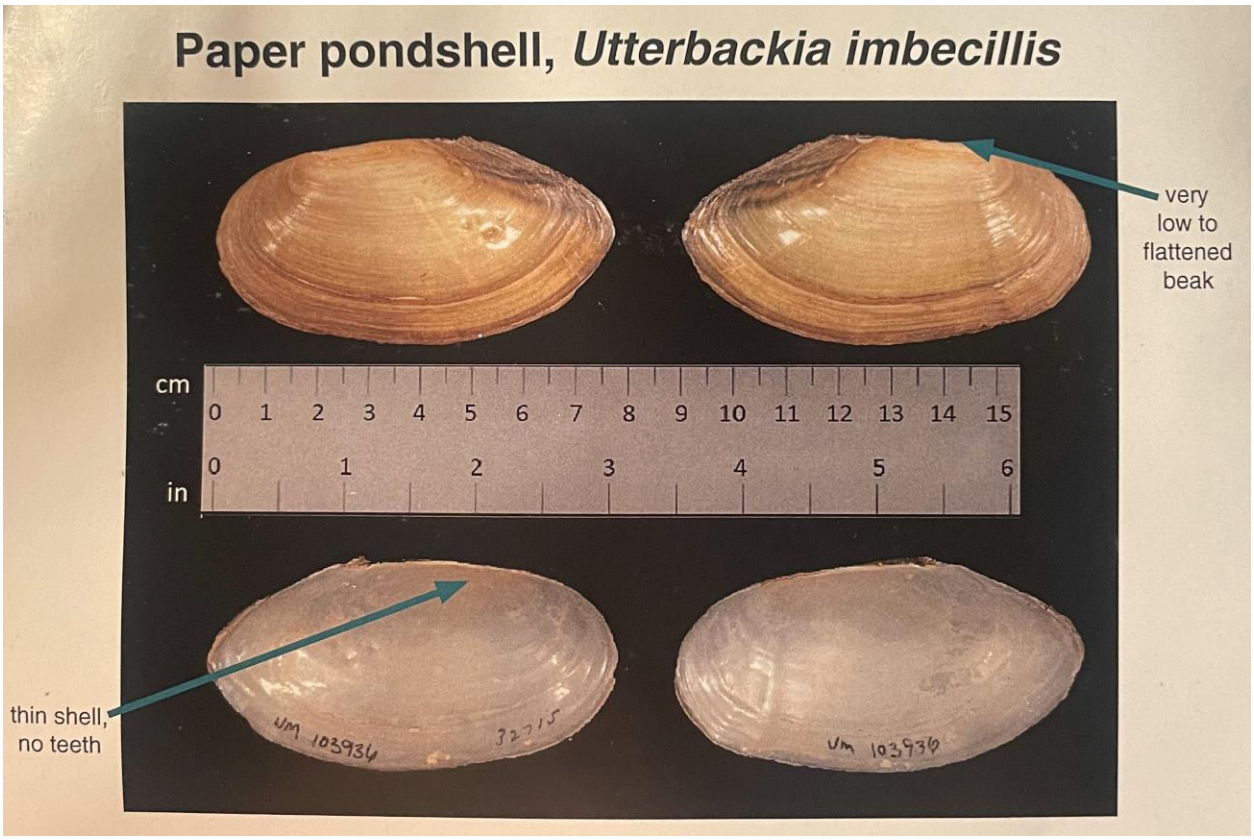
Size: up to 10 cm (4 in)

Shape: elliptical or oval; shell varies among individuals, have thicker shells when old

Color: greenish brown in young, brown to black in old

Rays: green rays in young

Additional features:



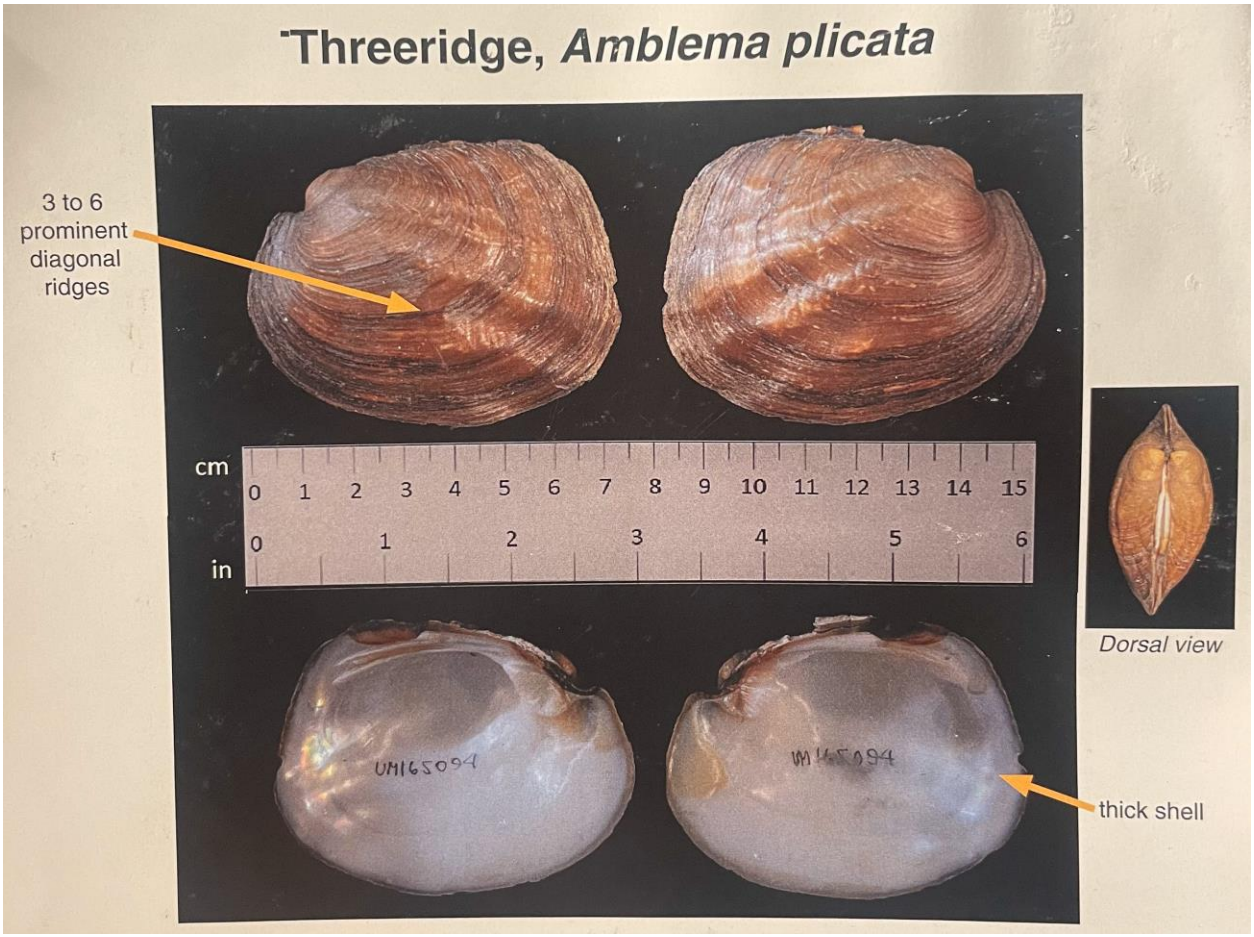
Paper pondshell, *Utterbackia imbecillis*

Size: up to 10 cm (4 in)

Shape: oblong, elongate and thin; shell compressed in young, inflated in old

Color: yellow in young, greenish yellow with yellow beak in old; black posterior slope

Rays: occasionally has green rays



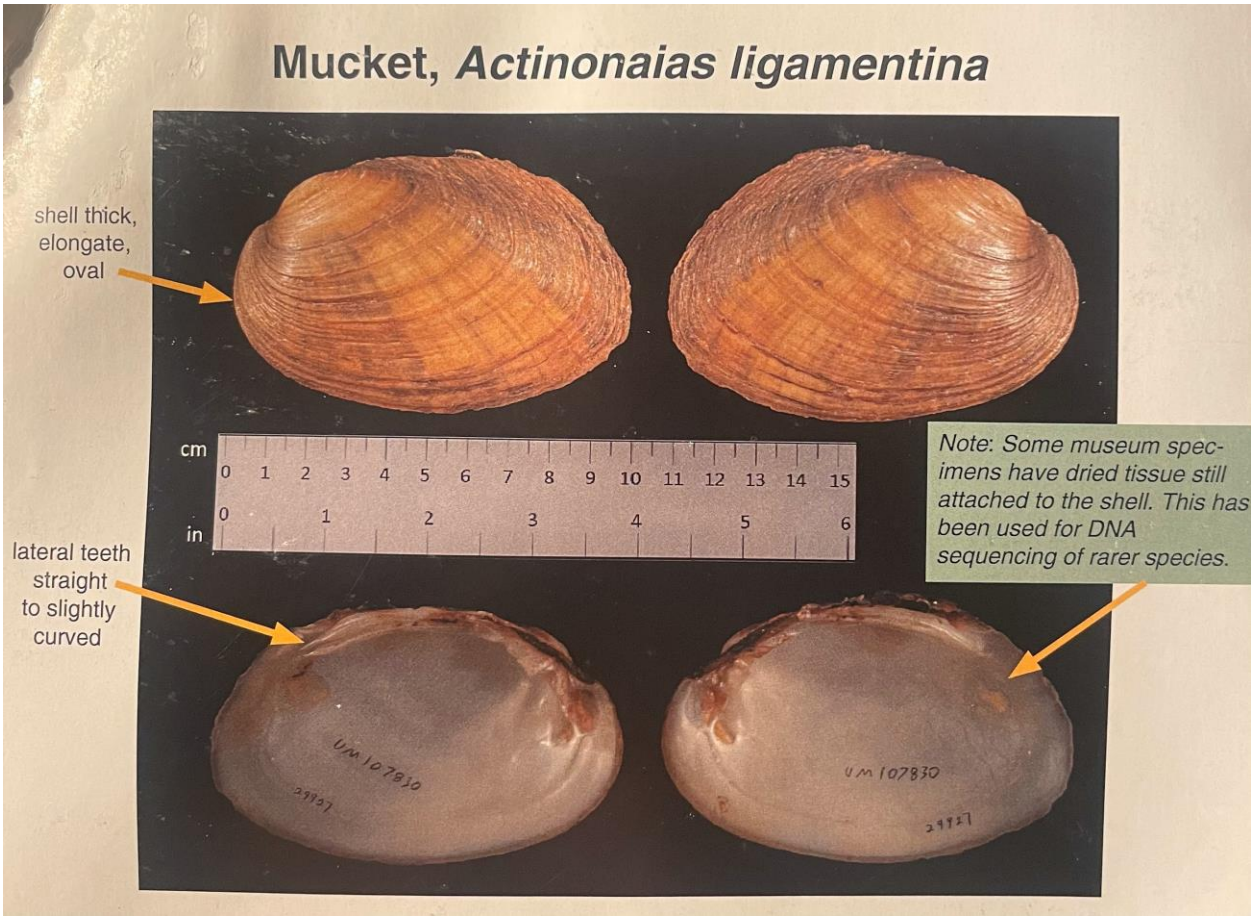
Threeridge, *Amblema plicata*

Size: up to 18 cm (7 in)

Shape: round or quadrate; thick shell

Color: brown or brownish black

Additional features: 3 to 6 prominent diagonal ridges



Mucket, *Actinonaias ligamentina*

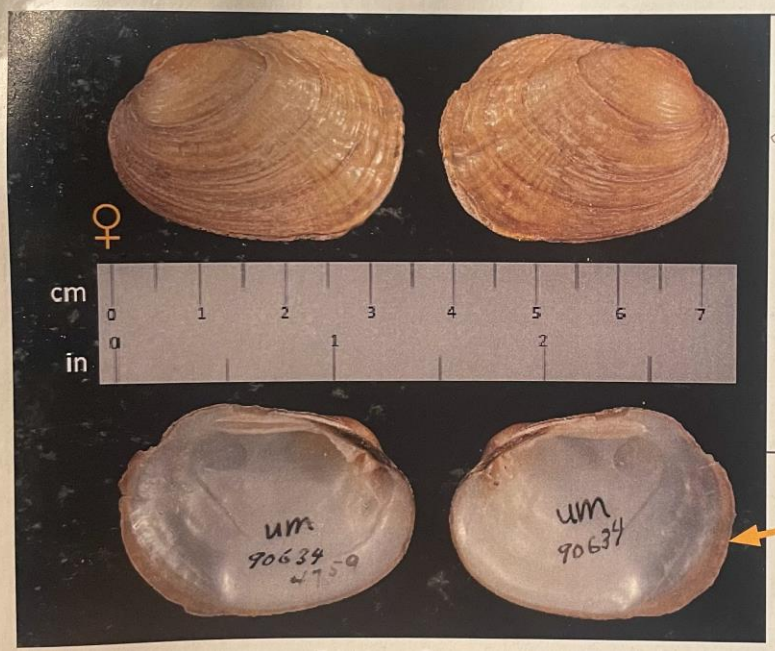
Size: up to 15 cm (7 in)

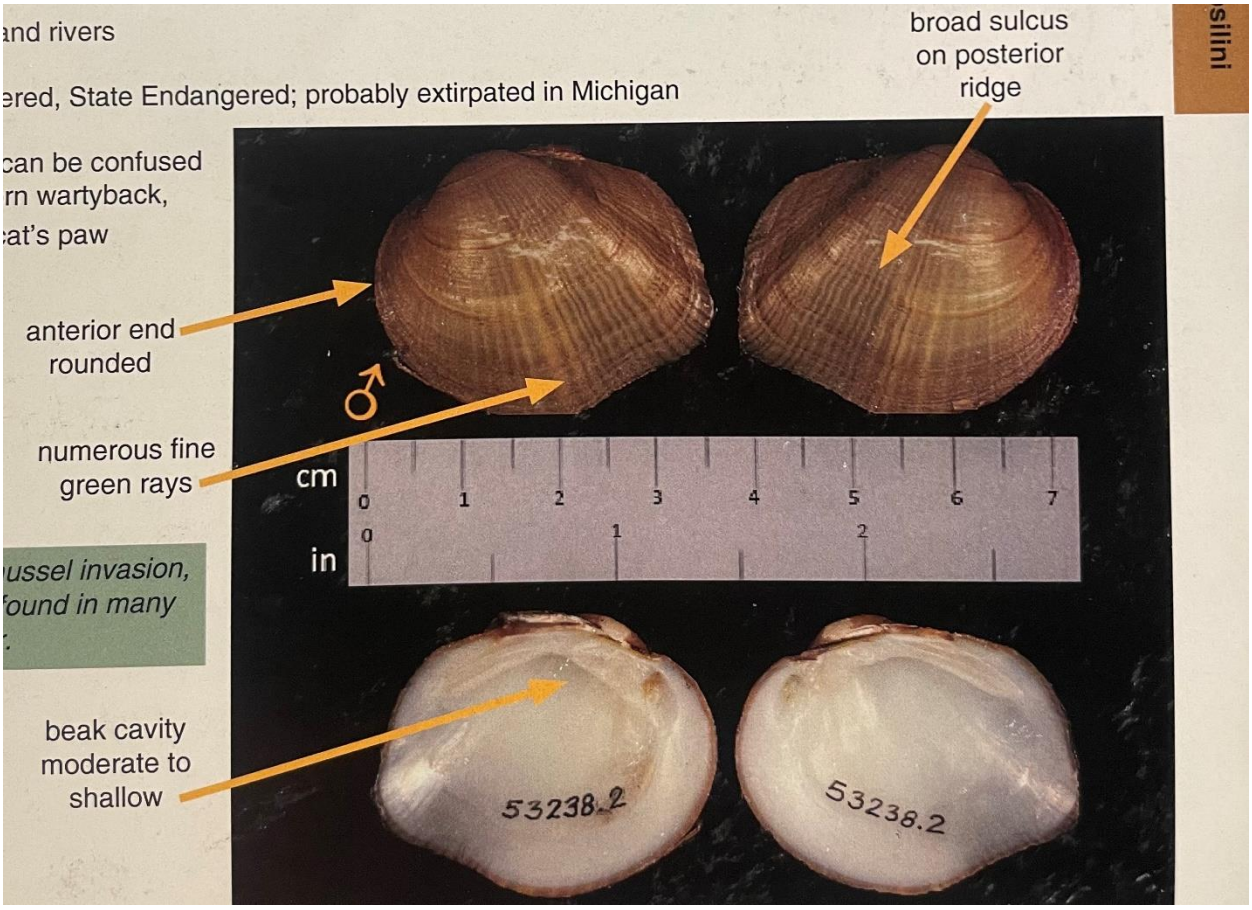
Shape: elongate, oval; thick shell

Color: yellowish brown to brown

Rays: often has green rays

Northern riffleshell, *Epioblasma rangiana*





and rivers

ered, State Endangered; probably extirpated in Michigan

can be confused
rn wartyback,
at's paw

ussel invasion,
found in many

silini

Northern riffleshell, *Eplioblasma torulosa rangiana* (Federally Endangered)

Size: up to 7.5 cm (3 in)

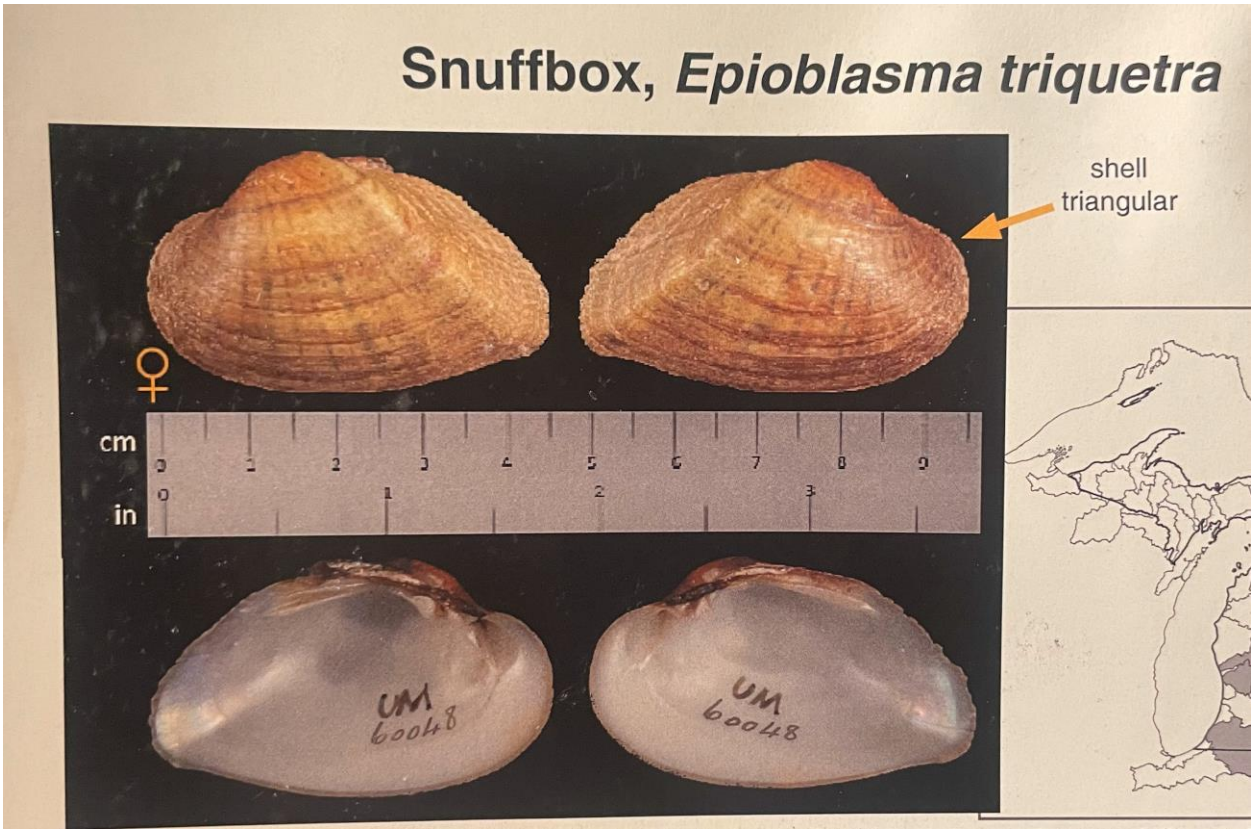
Shape: thick, compressed shell; sexually dimorphic*

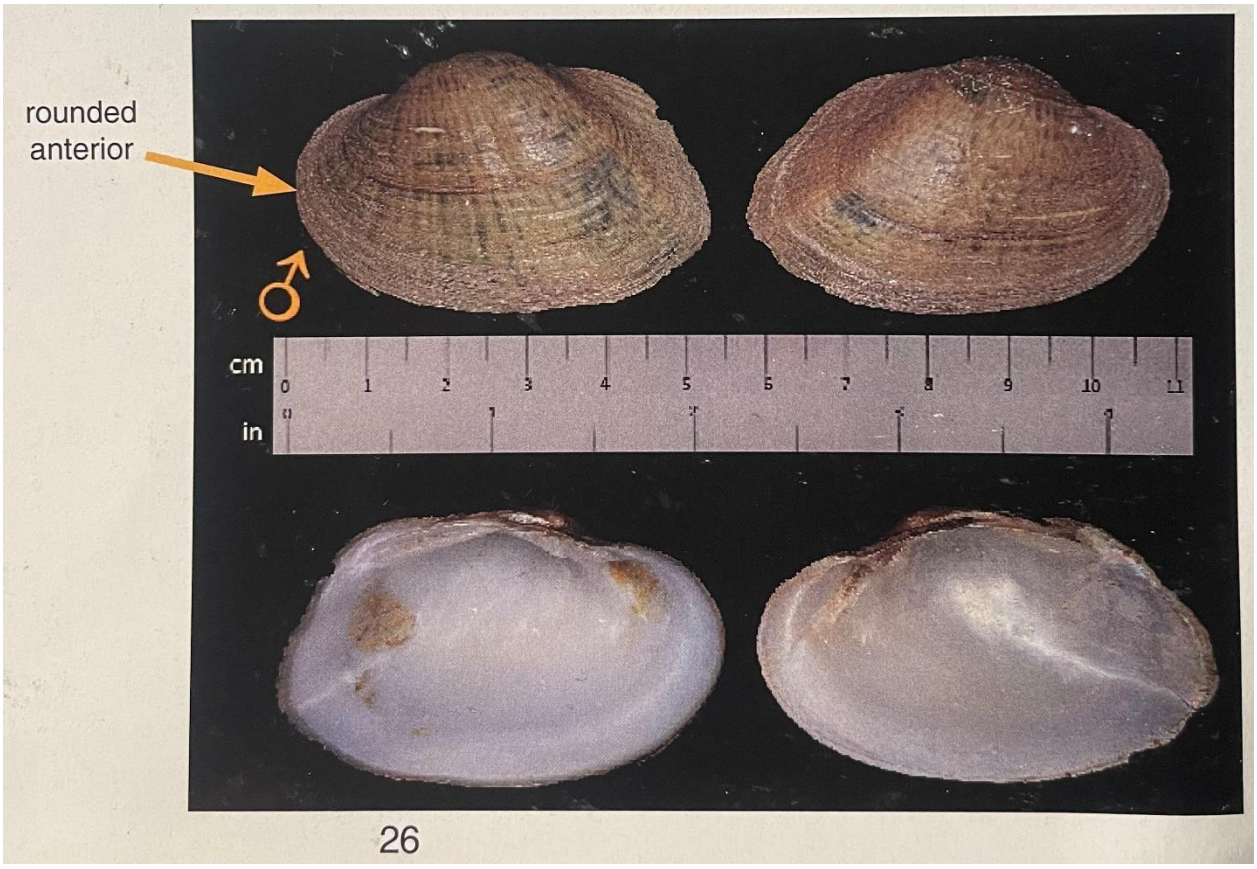
Color: green, yellow, or tan

Rays: numerous fine green rays

***Females**: oblong with broad, fragile posterior edge

***Males**: oblong with broad sulcus on posterior ridge


Snuffbox, *Epioblasma triquetra*
shell triangular
♀
cm
in
UM 60048
UM 60048


rounded anterior
♂
cm
in
26

Snuffbox, *Epioblasma triquetra* (Federally Endangered)

Size: up to 7.5 cm (3 in)

Shape: triangular or elongate; inflated shell; sexually dimorphic*

Color: yellow to yellowish green

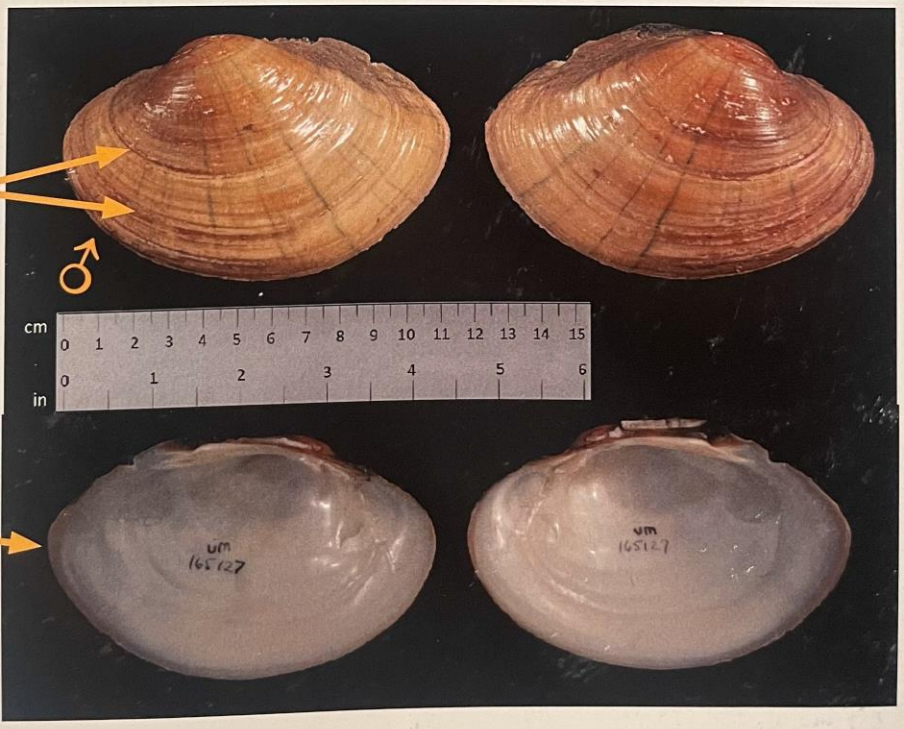
Rays: green rays and arrow shaped markings

***Females:** longer, angular posterior end; smaller than males

***Males:** shorter, round posterior end; larger than females

Plain pocketbook, *Lampsilis cardium*

Note: Plain pocketbooks are common, and usually "wow" people when they first see them, since they are relatively large.



Plain pocketbook, *Lampsilis cardium*

Size: up to 18 cm (7 in)

Shape: round or quadrate; inflated; thick in older specimens; sexually dimorphic*

Color: yellow to yellowish green

Rays: often has green rays

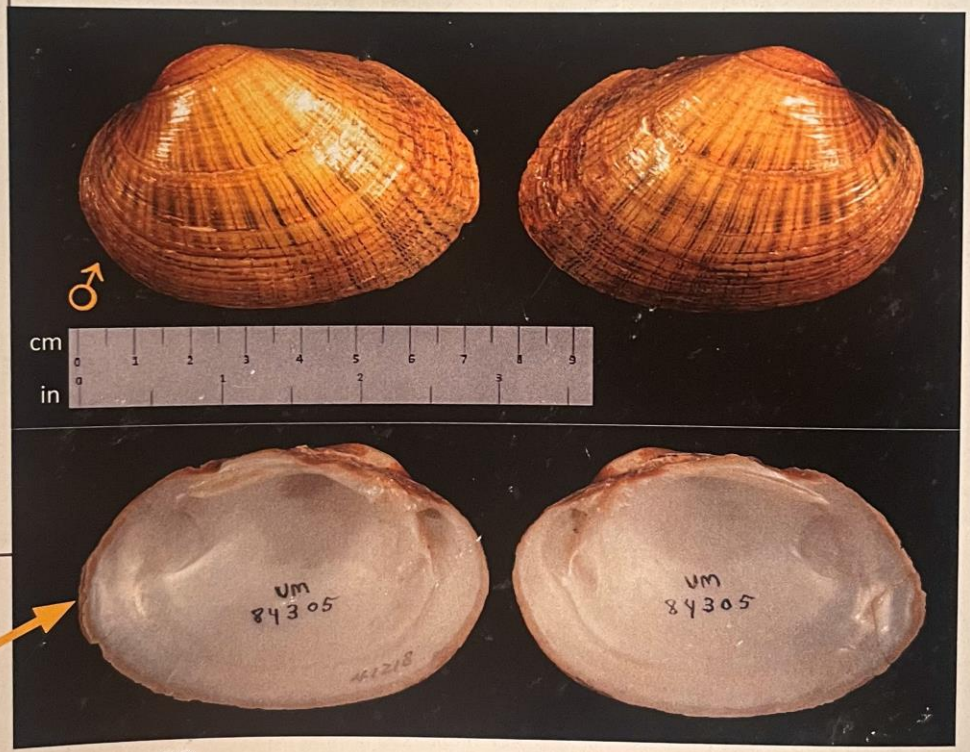
***Females:** round posterior end

***Males:** bluntly pointed posterior end

Wavy-rayed lampmussel, *Lampsilis fasciola*

shell has thin, wavy rays

Anterior view of male. Males are compressed, females inflated.



males have bluntly pointed posterior

29

Wavy-rayed lampmussel, *Lampsilis fasciola* (State Threatened)

Size: up to 7.5 cm (3 in)

Shape: round or oval; thick; sexually dimorphic*

Color: yellow to yellowish green in young, browner in old

Rays: thin wavy green rays

***Females**: inflated shell; round posterior end

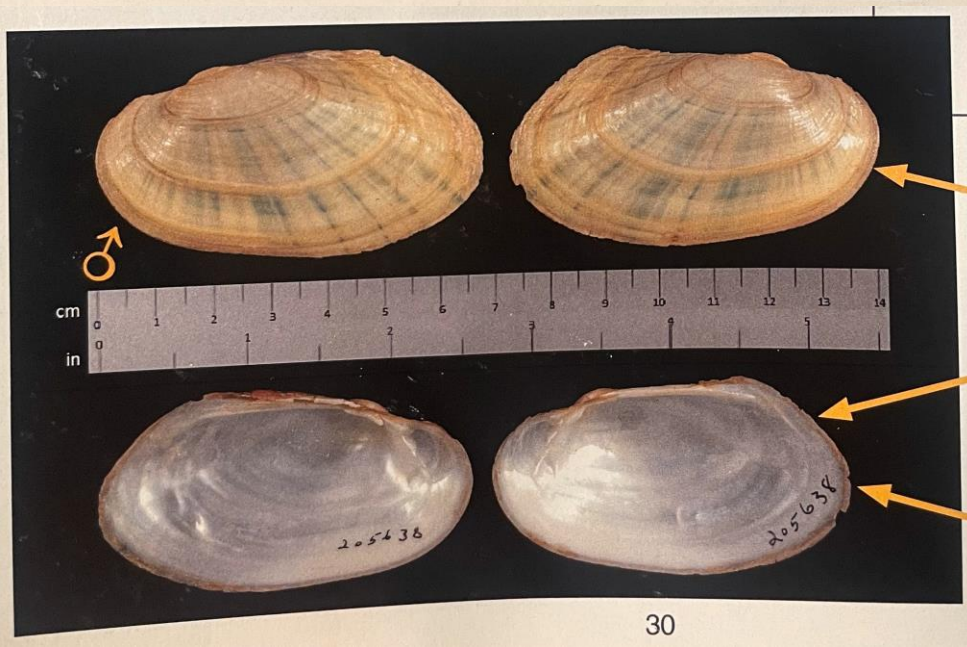
***Males**: compressed shell; bluntly pointed posterior end

Fat mucket, *Lampsilis siliquoidea*

pseudocardinal teeth erect, compressed (contrast to mucket, p.23)

Note: The fat mucket is one of the more common species in Michigan.

posterior end truncated in females



anterior end rounded

shell oblong, elliptical

posterior end bluntly pointed in males

Fat mucket, *Lampsilis siliquoidea*

Size: up to 13 cm (5 in)

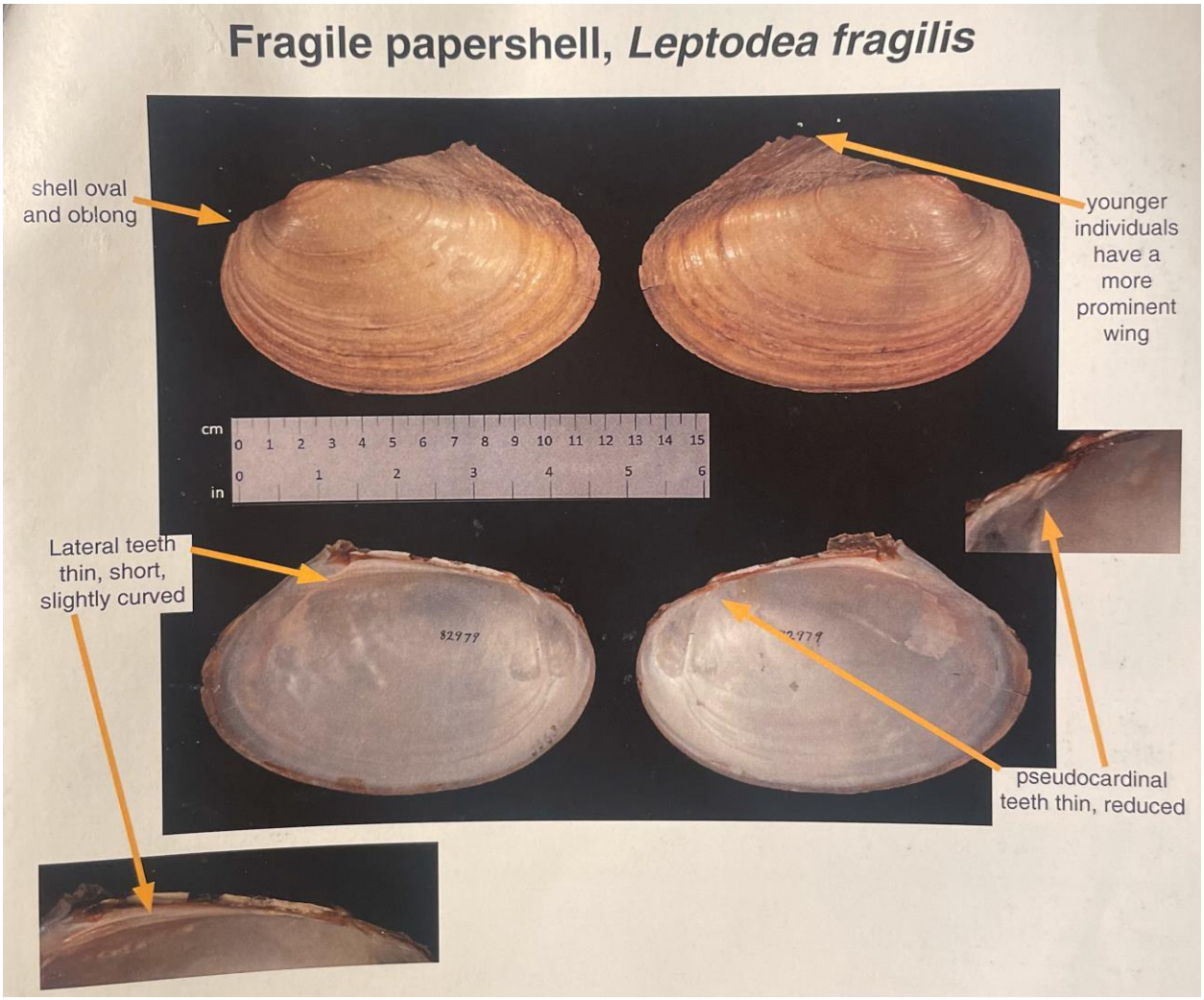
Shape: oblong, elliptical; varies between compressed or inflated; sexually dimorphic*

Color: yellow to yellowish green in young, brownish in old

Rays: green rays

***Females:** shorter**,** truncated posterior end

***Males**: bluntly pointed posterior end



Fragile papershell, *Leptodea fragilis*

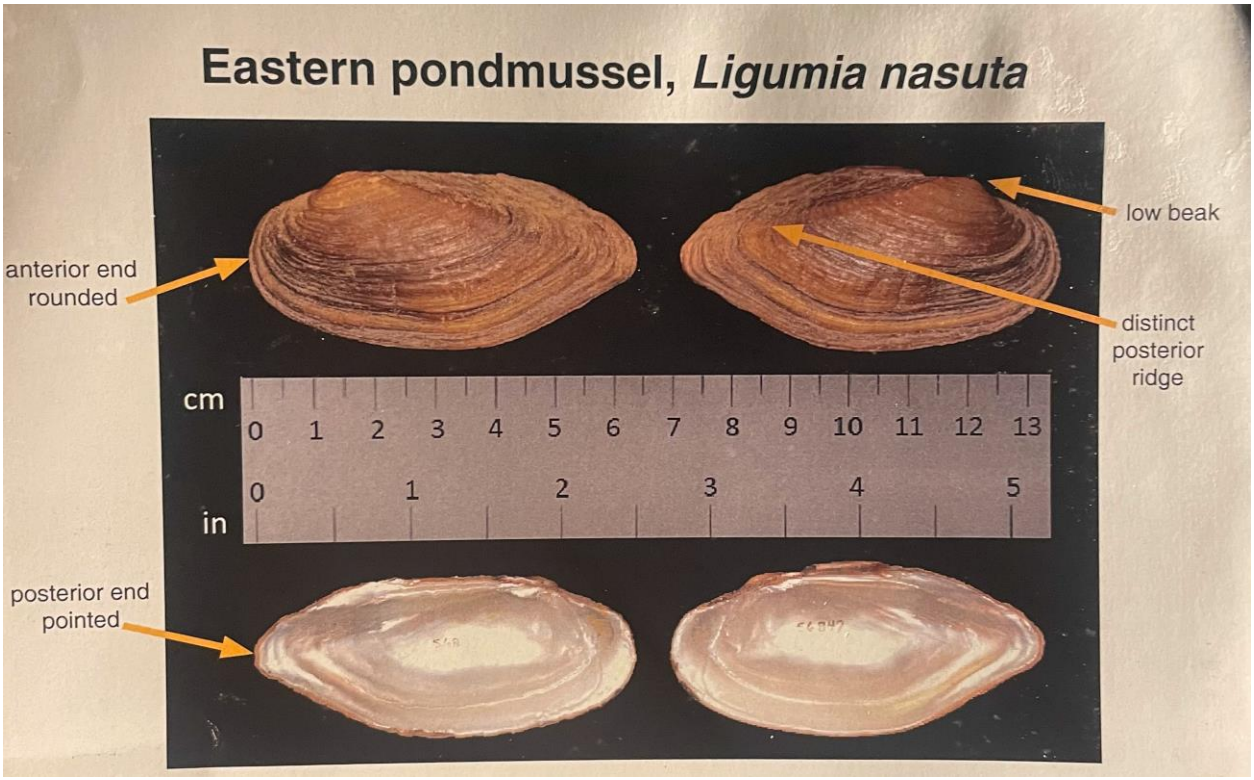
Size: up to 15 cm (6 in)

Shape: oval or oblong; thin and compressed

Color: yellowish tan to yellowish brown; beak often darker

Rays: sometimes faint green rays

Additional features: dorsal wing in young



Eastern pondmussel, *Ligumia nasuta* (State Endangered)

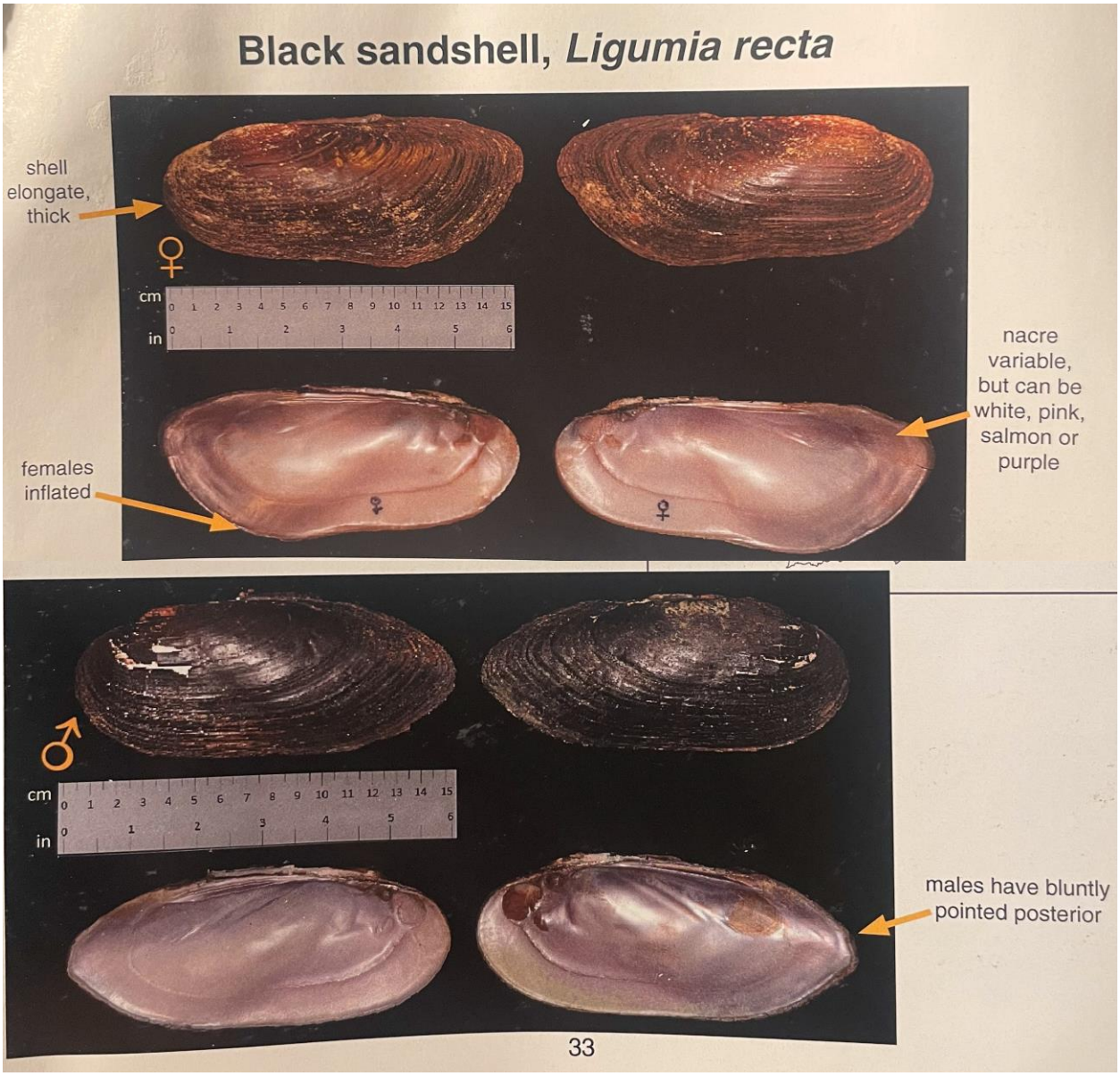
Size: up to 10 cm (4 in)

Shape: elongate and compressed (twice as long as it is high)

Color: tan to dark green, darker in older specimens

Rays: sometimes green rays

Additional features: distinct posterior ridge



Black sandshell, *Ligumia recta* (State Endangered)

Size: up to 25 cm (10 in)

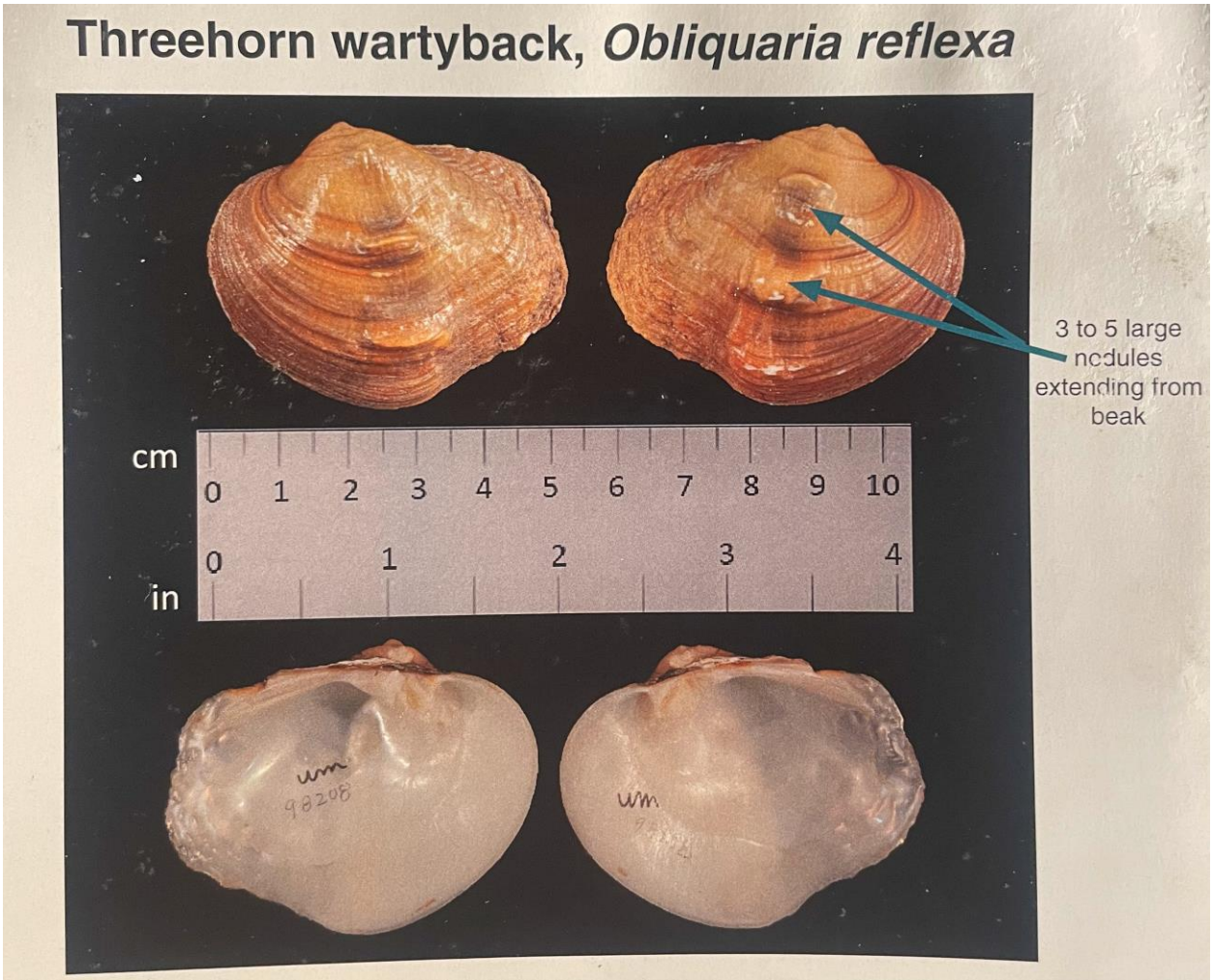
Shape: elongate, quadrate; thick and somewhat inflated; sexually dimorphic*

Color: dark green or brown, darker in older specimens

Rays: sometimes green rays

***Females:** inflated posterior end

***Males**: bluntly pointed posterior end



Threehorn wartyback, *Obliquaria reflexa* (State Endangered)

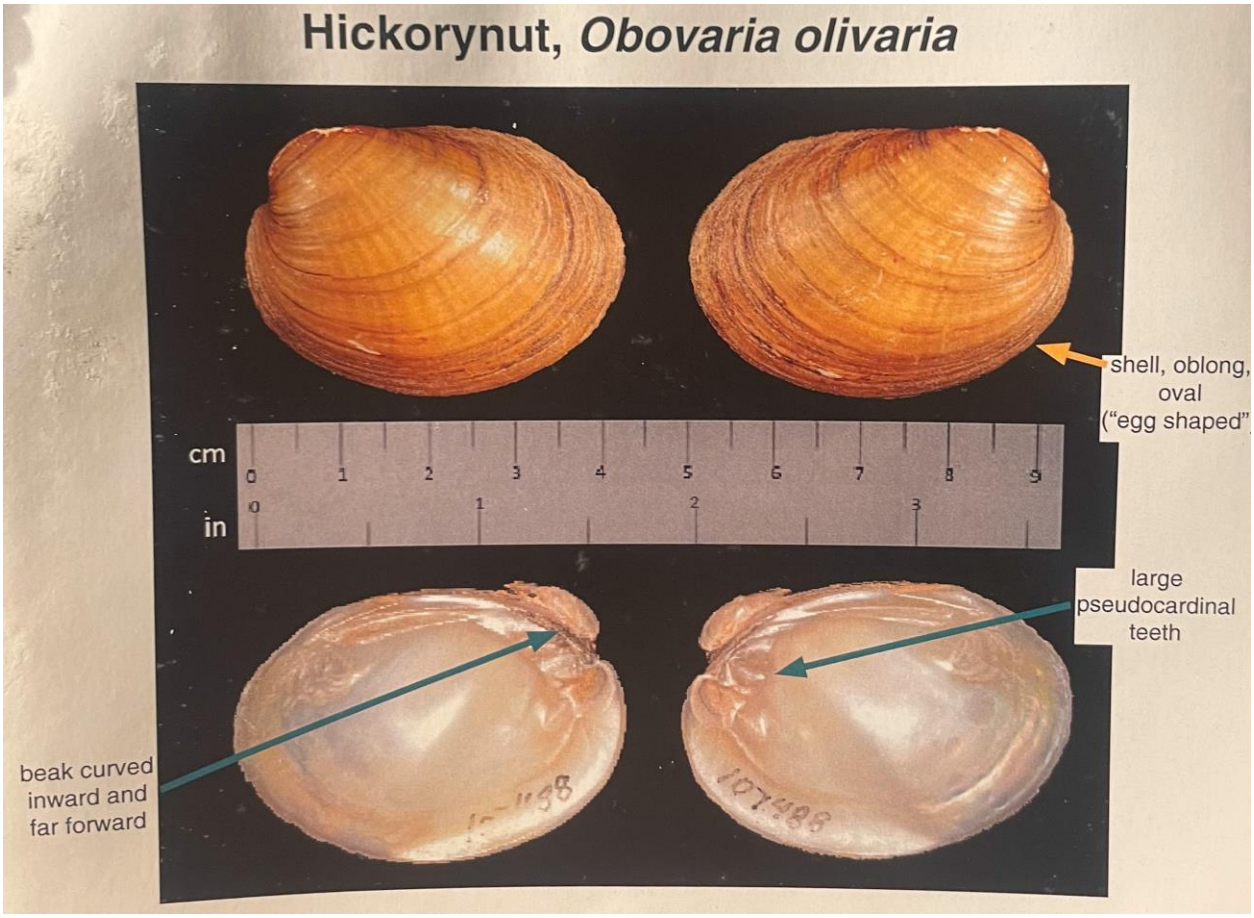
Size: up to 7.5 cm (3 in)

Shape: round, thick, inflated

Color: light yellowish brown to green, darker in older specimens

Rays: thin broken green rays

Additional features: 3-5 large nodules coming out from the beak, often with depressions in between each nodule; serrated posterior slope; beak slightly pointing in towards ridge



Hickorynut *Obovaria olivaria* (State Endangered)

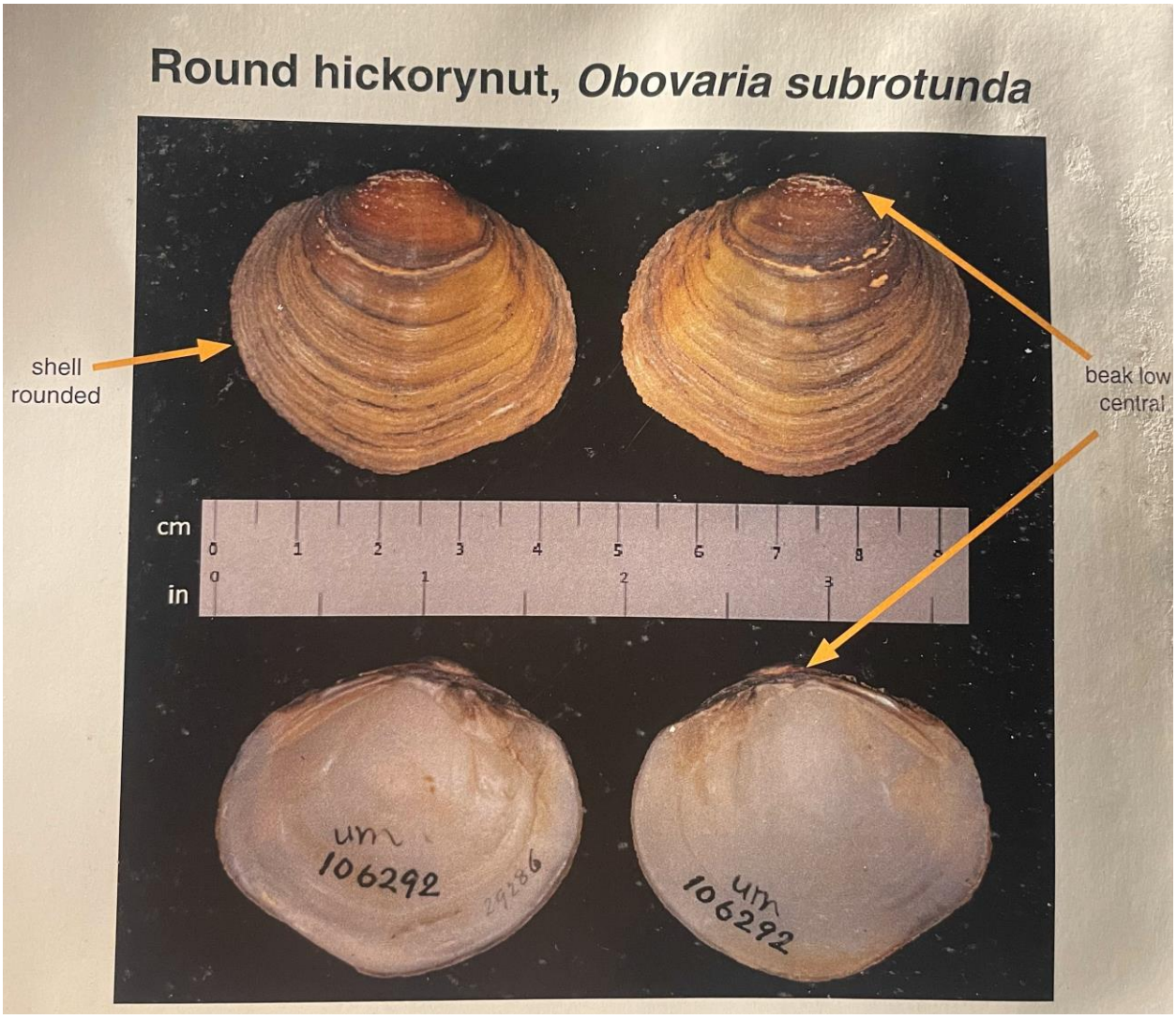
Size: up to 10 cm (4 in)

Shape: oblong or oval; thick and inflated

Color: olive brown to yellowish brown; darker in older specimens

Rays: occasionally faint green rays in young

Additional features: low curved beak



Round hickorynut, *Obovaria subrotunda* (Federally Threatened, State Endangered)

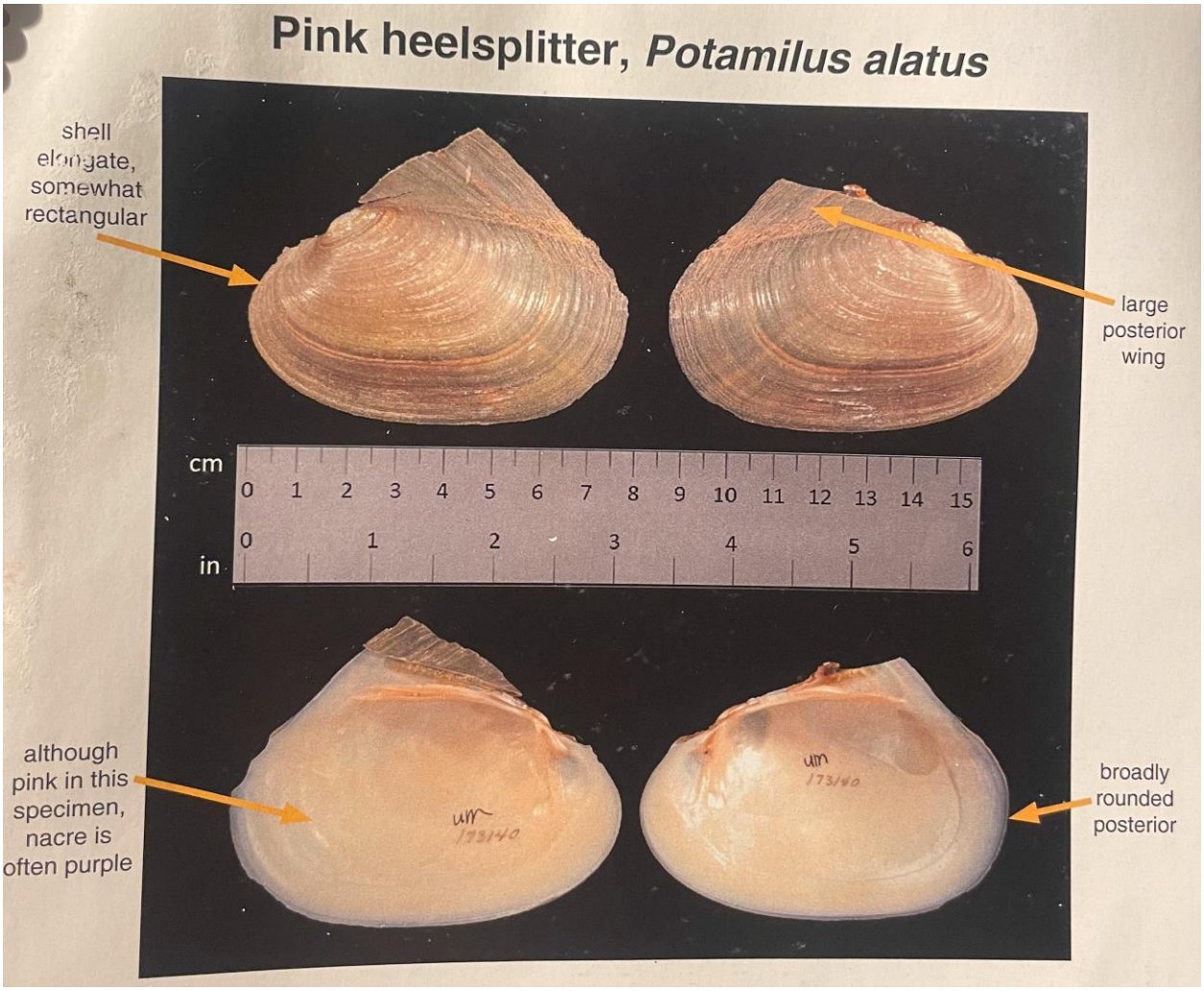
Size: up to 7.5 cm (3 in)

Shape: round and inflated

Color: yellow to yellowish brown, darker in older specimens

Females: truncated posterior end

Males: rounded posterior end



Pink heelsplitter, *Potamilus alatus*

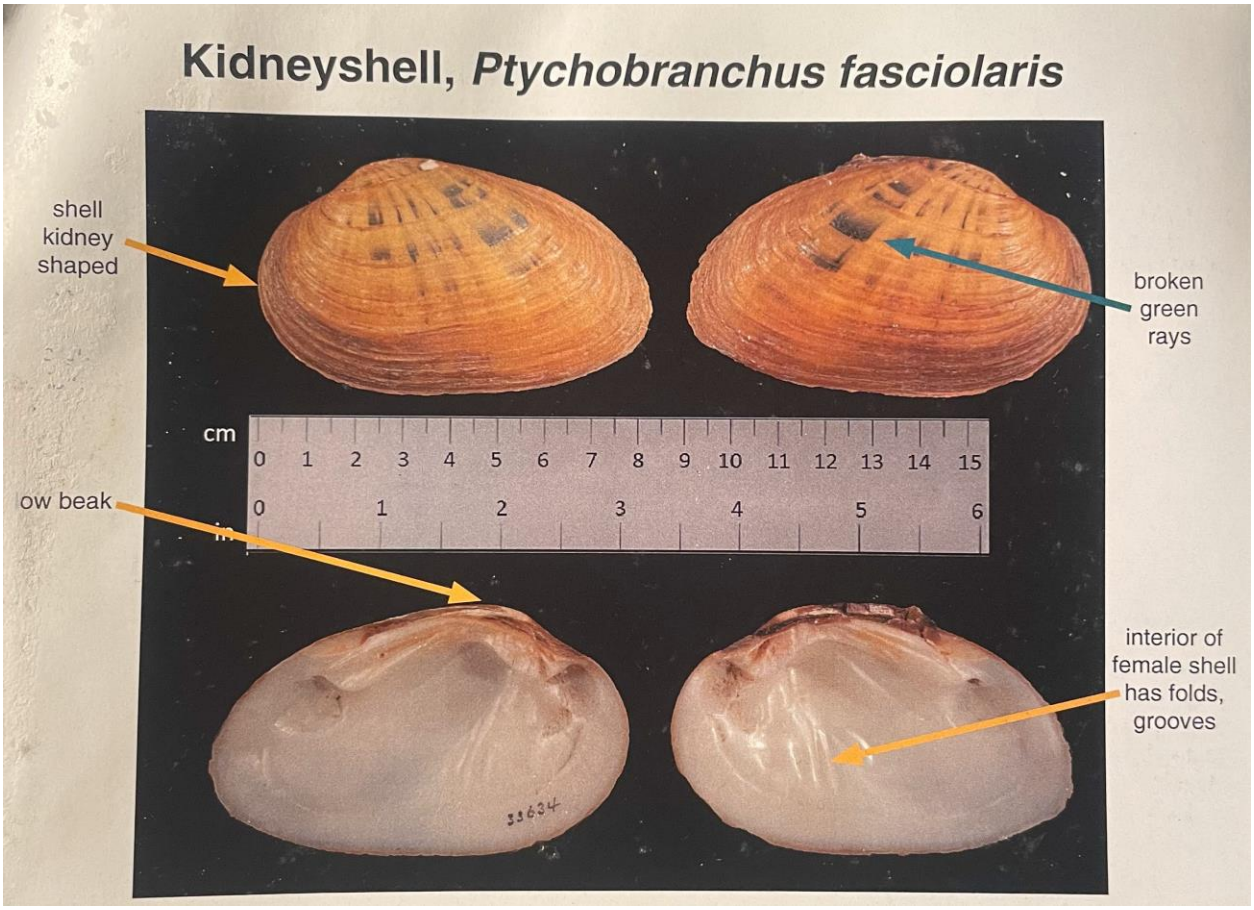
Size: up to 20 cm (8 in)

Shape: elongate and somewhat rectangular; compressed

Color: dark green or brown, darker in older specimens

Rays: green rays

Additional features: large prominent posterior wing



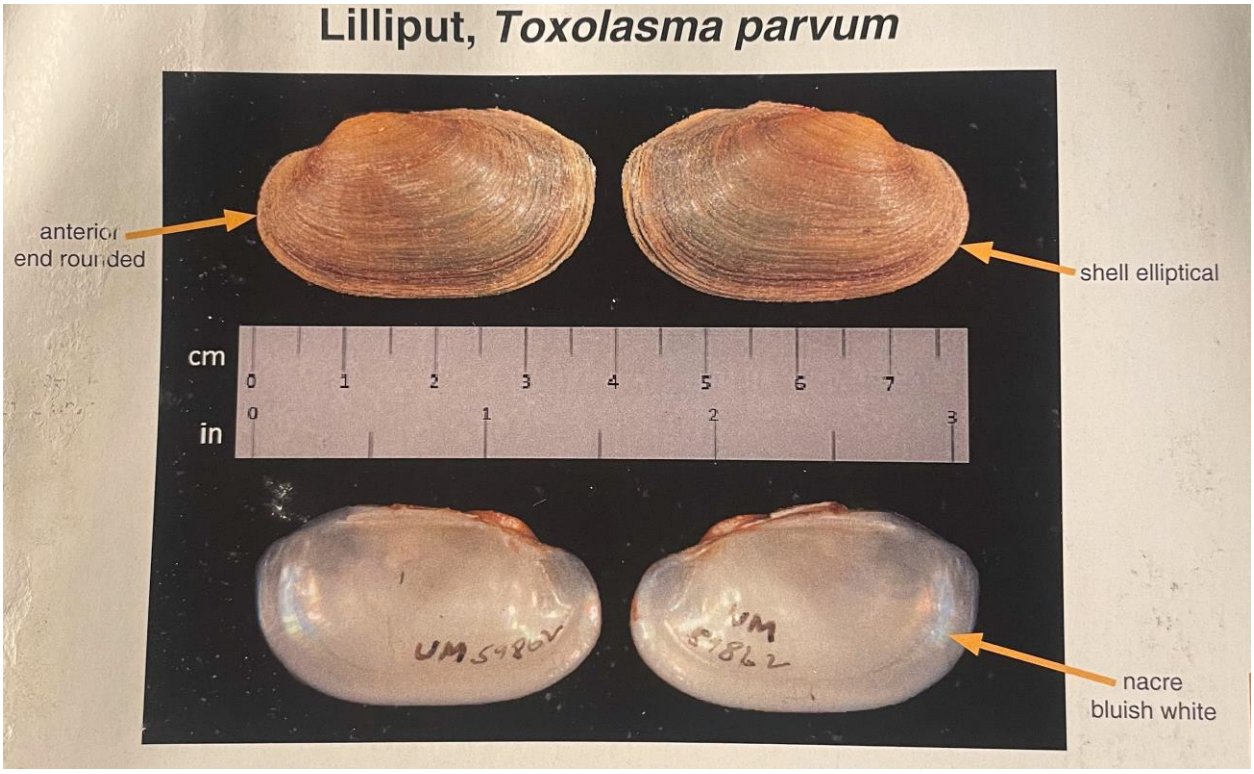
Kidney-shell, *Ptychobranchus fasciolaris* (State Special Concern)

Size: up to 15 cm (6 in)

Shape: elongate and kidney-shaped; thick and compressed

Color: yellow to brown

Rays: broken green rays

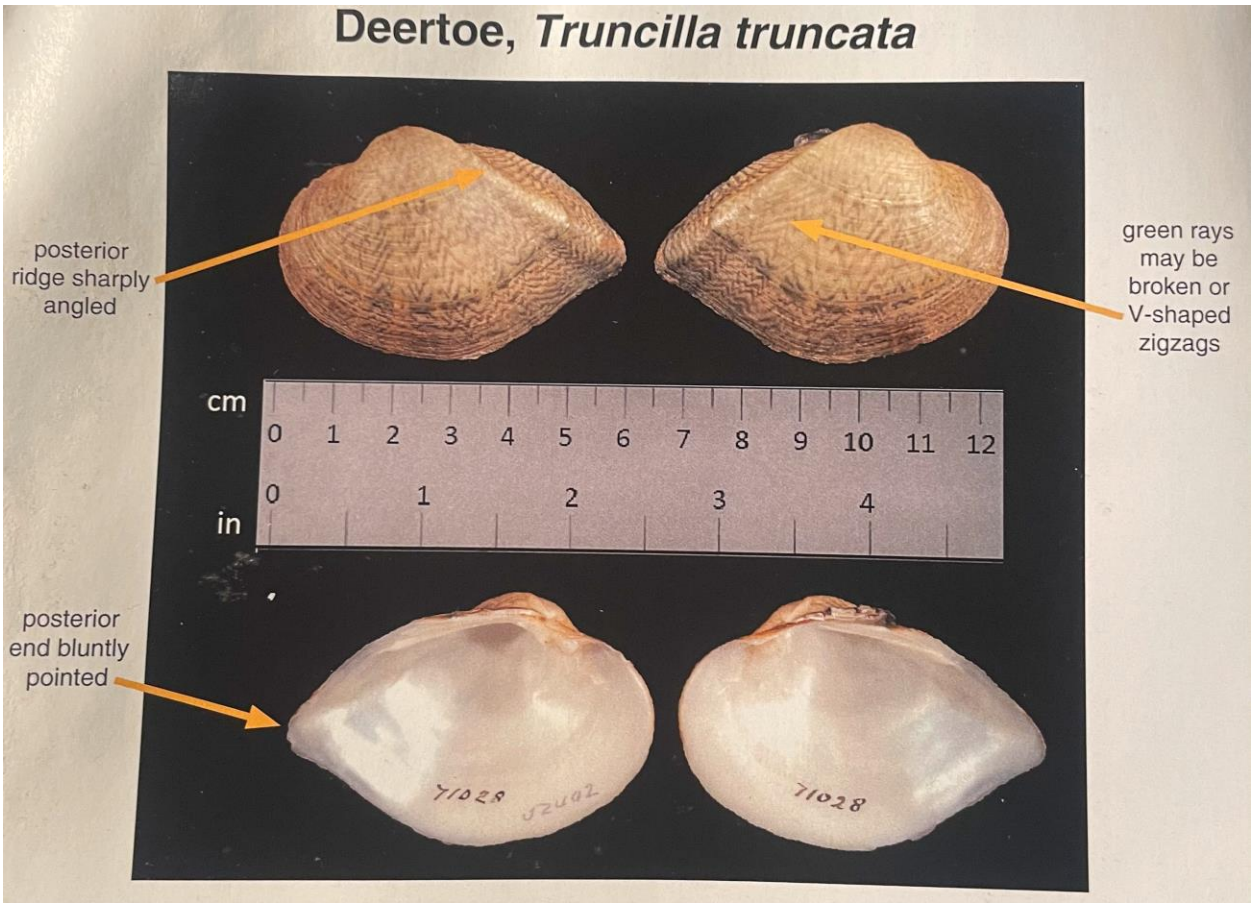


Liliput, *Toxolasma parvum* (State Endangered)

Size: up to 4 cm (1.5 in)

Shape: elliptical, cylindrical; moderately inflated in males and more inflated in females

Color: dark green or brown with a satin-like shine, darker in older specimens



Deertoe, *Truncilla truncata* (State Special Concern)

Size: up to 5 cm (2 in)

Shape: triangular; moderately inflated and fairly thick

Color: yellow, green, or brown

Rays: many green rays often broken or as V-shaped zigzags

Additional features: sharply angled posterior ridge; prominent and raised beak

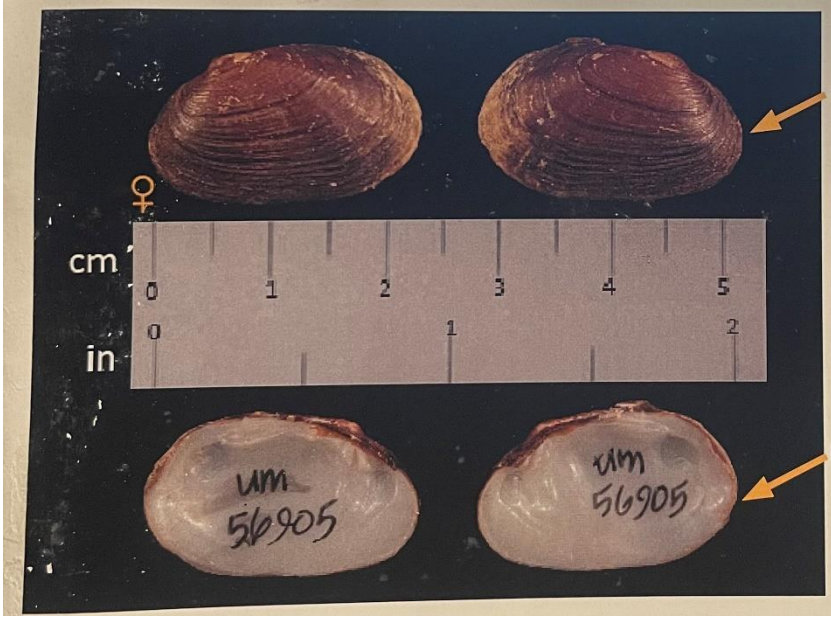
Rayed bean, *Villosa fabalis*

anterior end rounded in both males and females

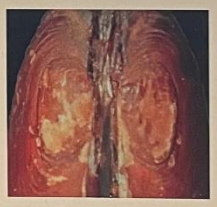
beak sculpture 2-3 heavy ridges

posterior end rounded in females

Rayed bean, *Villosa fabalis*



anterior end rounded in both males and females



beak sculpture 2-3 heavy ridges

posterior end rounded in females

Rayed bean, *Villosa fabalis* (Federally Endangered)

Size: up to 4 cm (1.5 in)

Shape: elliptical; thick and inflated; sexually dimorphic*

Color: yellowish green or brown

Rays: many green wavy rays

***Females**: round posterior end; more inflated

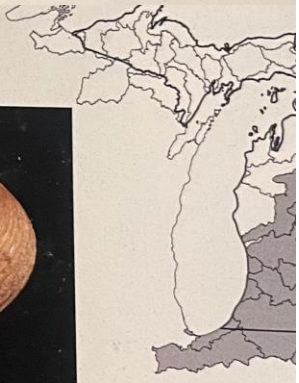
***Males**: tapered posterior end; less inflated

Rainbow, *Villosa iris*

anterior end rounded in both males and females

posterior end rounded in females

Note: The rainbow is fo Erie drainages; the ver is not.



bluntly pointed posterior

heavy, broken rays

low beak

Rainbow, *Villosa iris* (Special Concern)

Size: up to 7.5 cm (3 in)

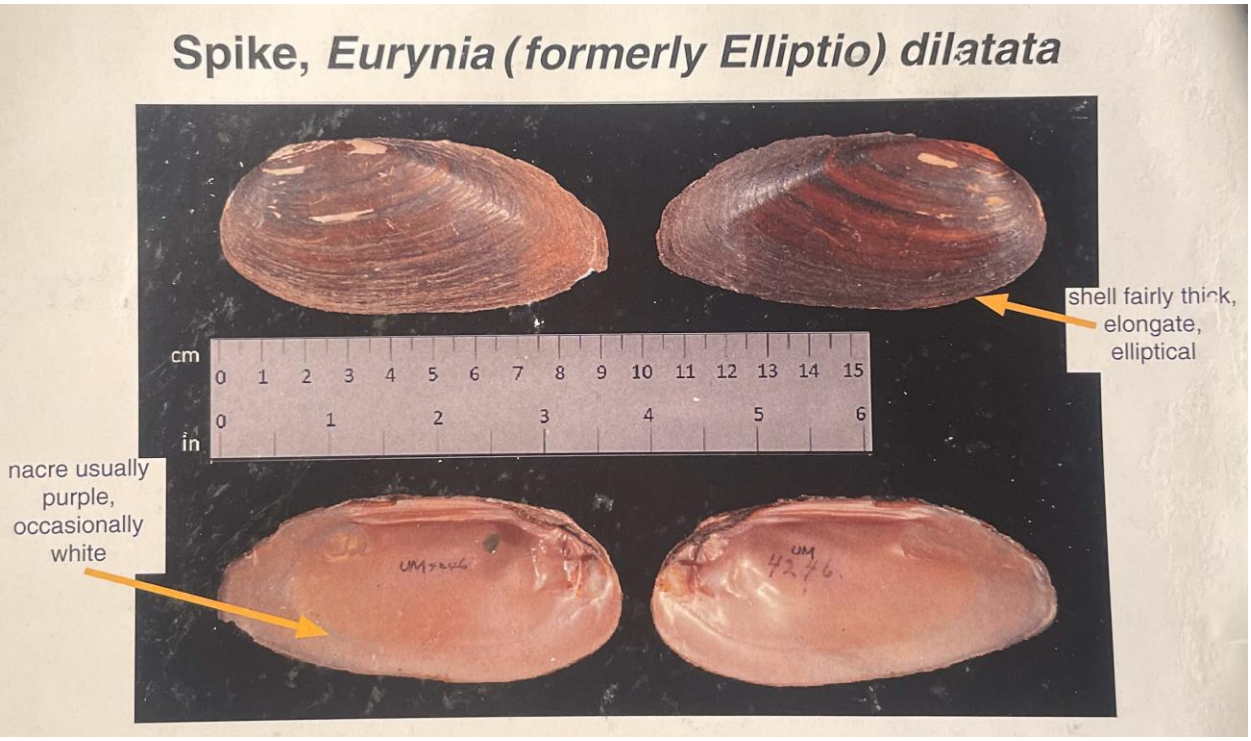
Shape: elongate, oblong, thin; sexually dimorphic*

Color: yellow to yellowish green

Rays: thick broken rays that are more numerous of the posterior side of the shell

Females: round posterior end

Males: bluntly pointed posterior end

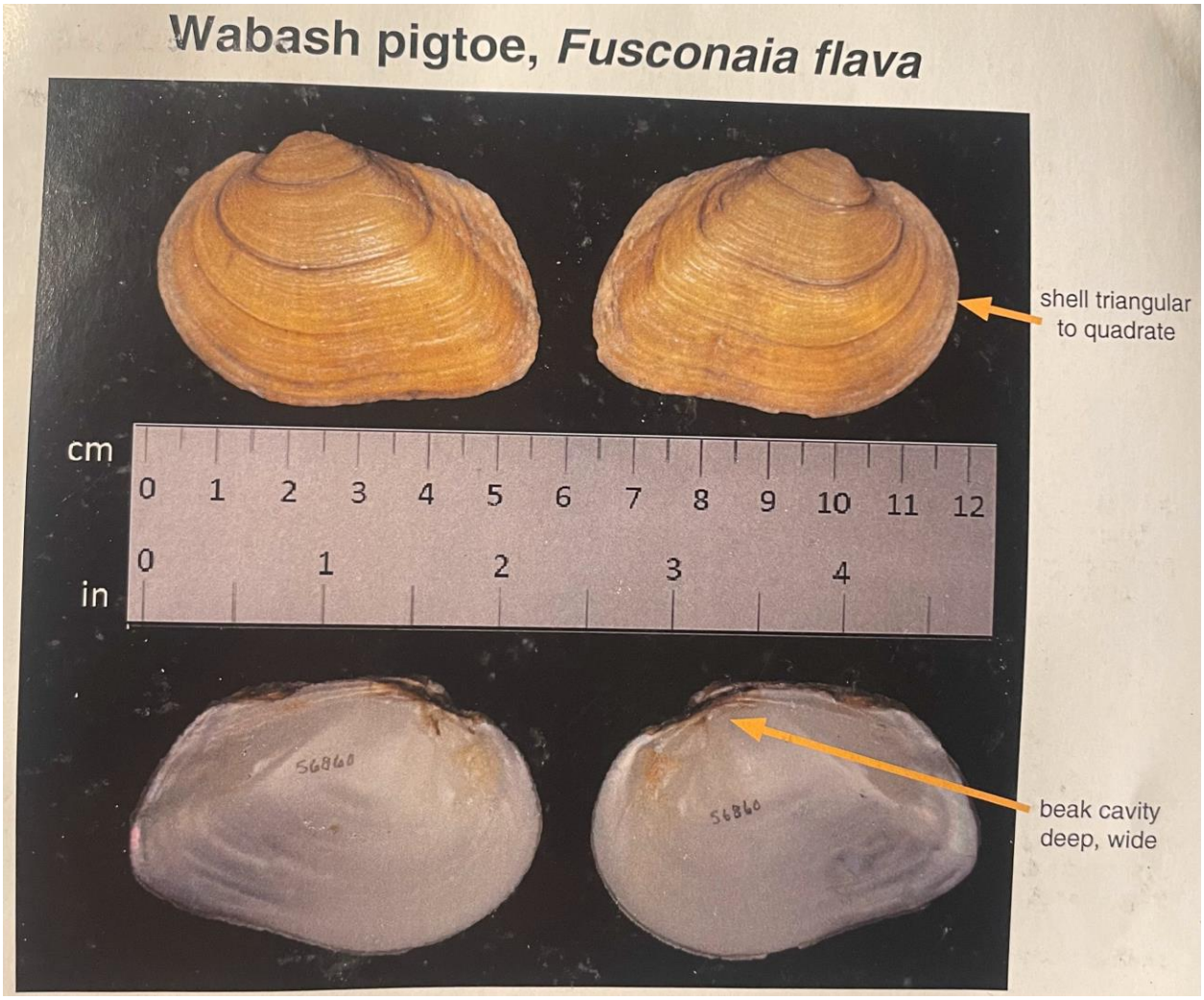


Spike, *Eurynia dilatata*

Size: up to 13 cm (5 in)

Shape: elongate, elliptical, fairly thick

Color: greenish brown in young, dark brown to black in old



Wabash pigtoe, *Fusconaia flava*

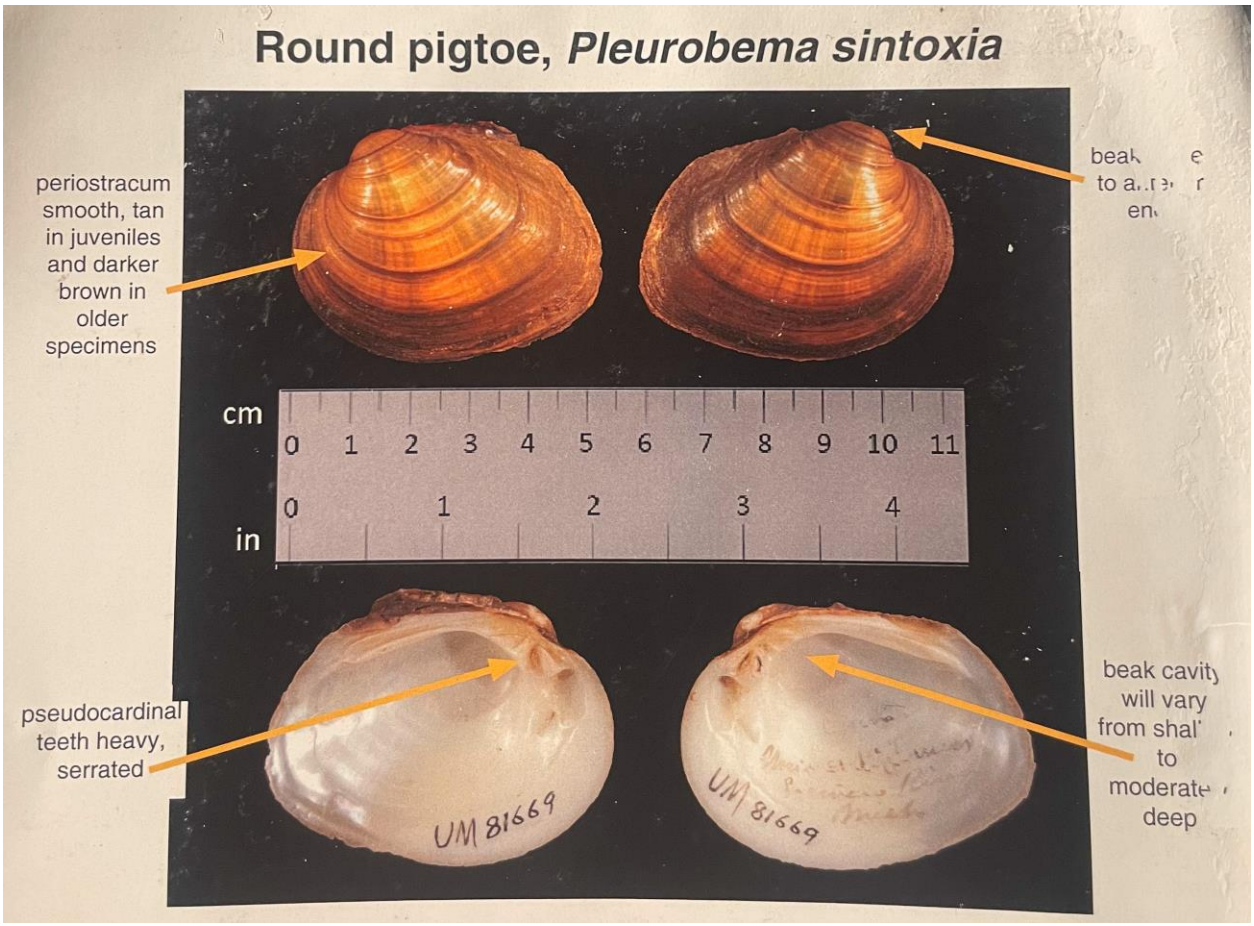
Size: up to 7.5 cm (3 in)

Shape: triangular to quadrate; thick and compressed

Color: yellowish brown to dark brown

Rays: faint green rays in young

Additional features: headwater specimens more round, large river speciemens more angunlar with prominent posterior ridge



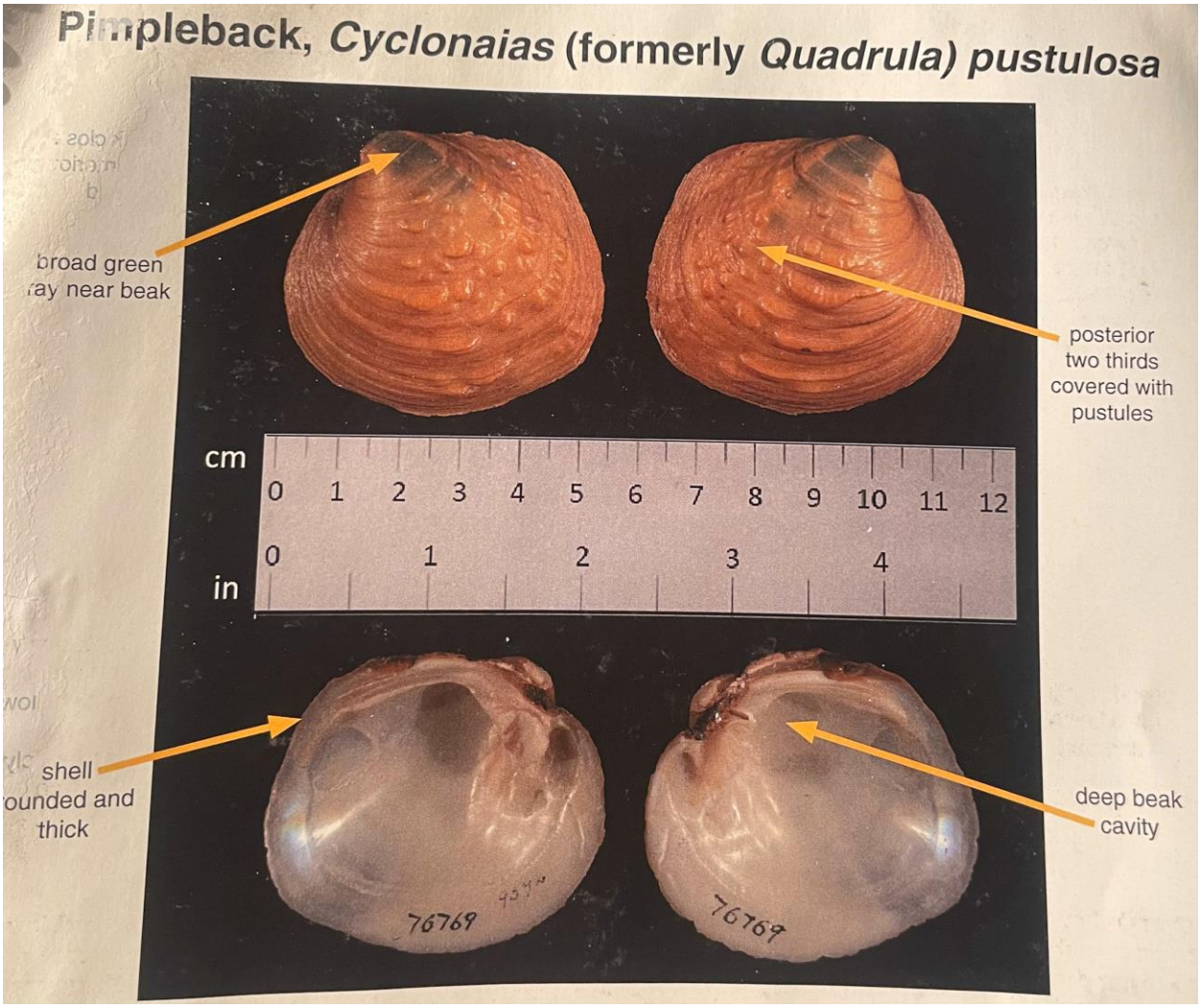
Round pigtoe, *Pleurobema sintoxia* (Special Concern)

Size: up to 10 cm (4 in)

Shape: shape varies with habitat: oval and compressed in small streams, triangular and inflated in large rivers; fairly thick; beak is centered or closer to anterior end

Color: tan in young, dark brown in old

Rays: occasionally has green rays



Pimpleback, *Quadrula pustulosa*

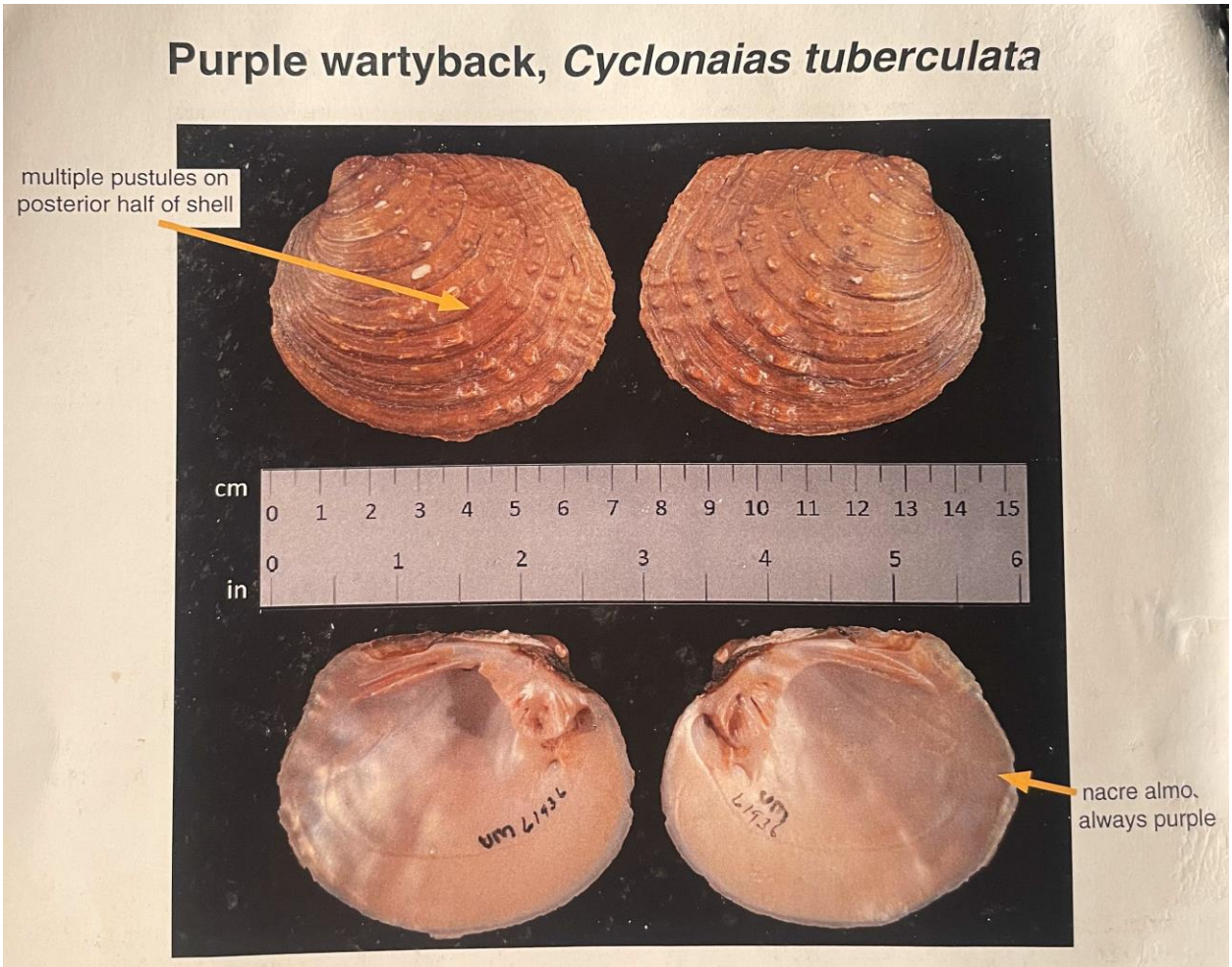
Size: up to 10 cm (4 in)

Shape: round and thick; shell varies from compressed to moderately inflated

Color: light brown

Rays: one broad green ray near beak; broken green rays in juveniles

Additional features: 2/3 of posterior end is covered with pustules



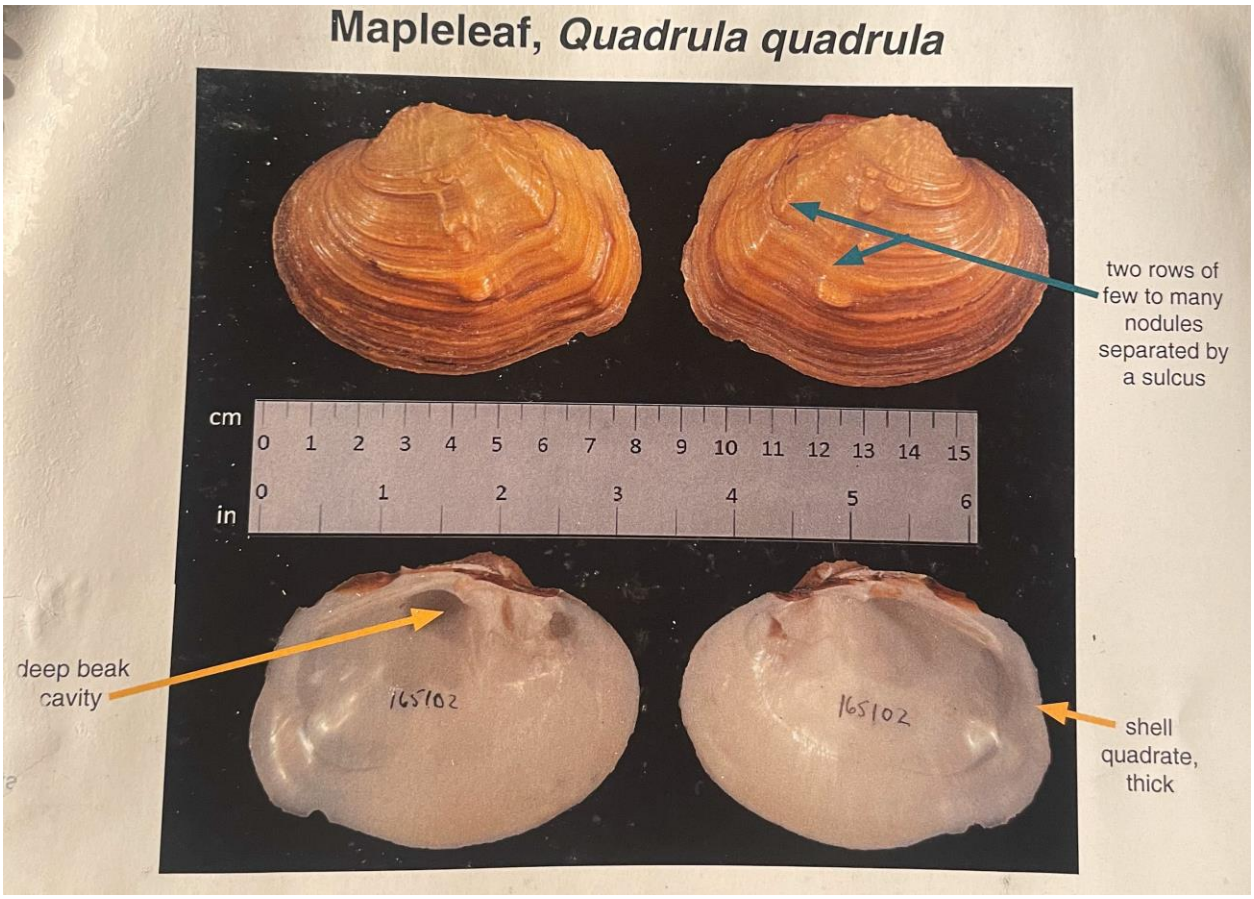
Purple wartyback, *Cyclonaias tuberculata* (State Threatened)

Size: up to 13 cm (5 in)

Shape: round, compressed, thick

Color: yellowish brown to greenish brown in young, darker brown in old

Additional features: posterior half is covered in multiple pustules; ridged dorsal wings



Mapleleaf, *Quadrula quadrula*

Size: up to 10 cm (4 in)

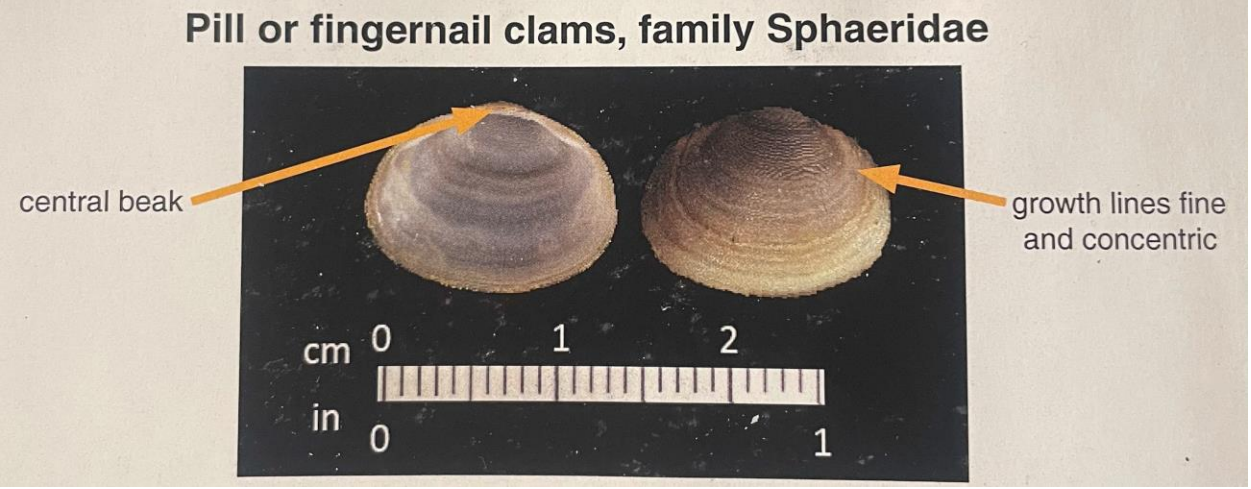
Shape: quadrate, thick, moderately inflated

Color: yellow, yellowish green, or brown

Rays: faint green rays in young

Additional features: two rows of nodules

Other bivalve species in Michigan



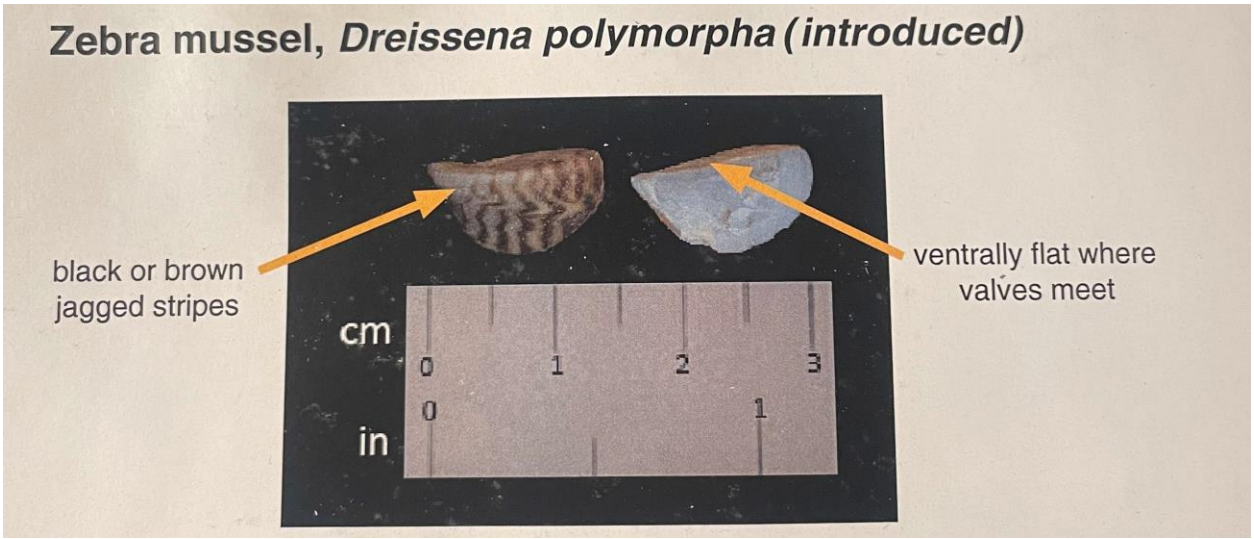
Pill or fingernail clams, family Sphaeridae (Native species)

Size: up to 1.5 cm (0.5 in)

Shape: round to slightly oval; inflated

Color: whitish or cream-colored

Additional features: very fine growth lines



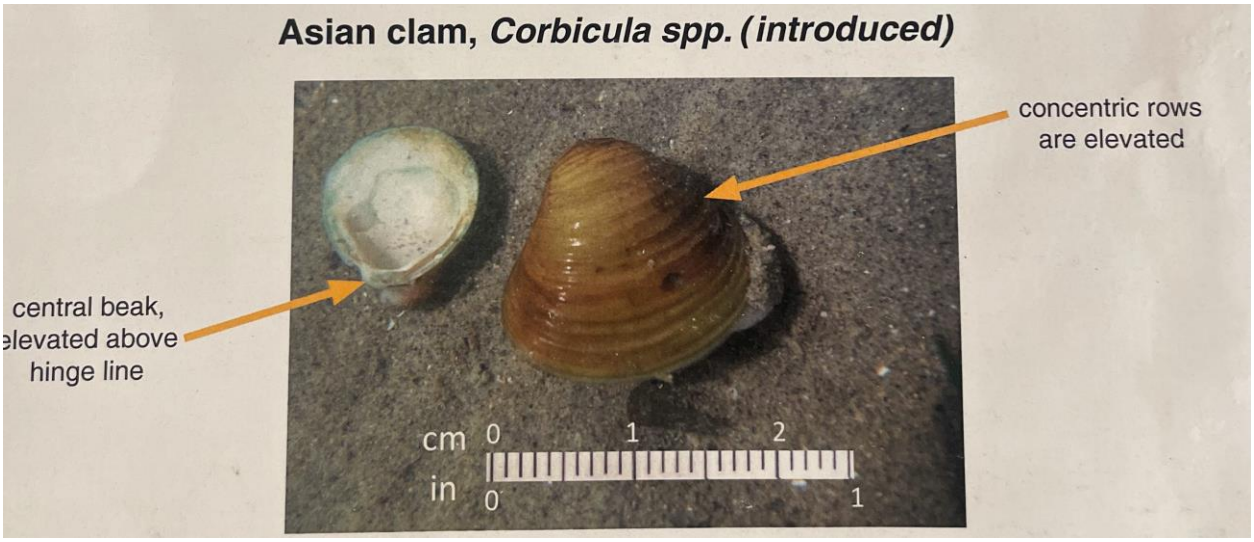
Zebra mussel, *Dreissena polymorpha* (Introduced species)

Size: up to 4 cm (1.5 in)

Shape: elongate, triangular, inflated

Color: white or cream-colored

Additional features: lateral brown or black, often jagged stripes; sharp dorsal end; sharply angled ridge from beak to posterior end; attach to hard substrate (often on unionids)



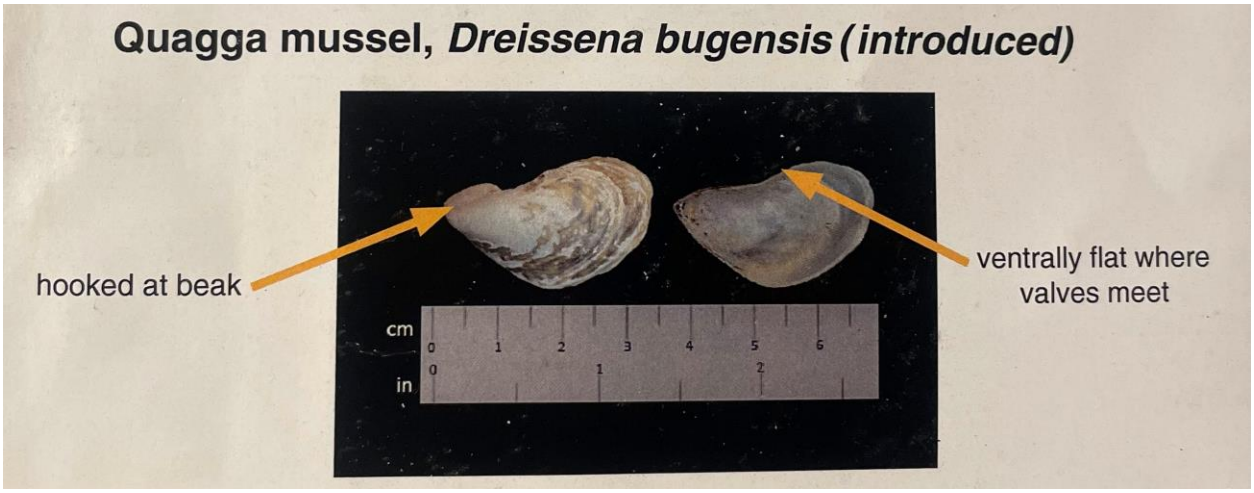
Asian clam, *Corbicula* spp. (Introduced species)

Size: up to 4 cm (1.5 in)

Shape: triangular, inflated

Color: yellowish brown to black

Additional features: numerous rows of elevated lines; beak highly raised above hinge line



Quagga mussel, *Dresissena bugensis* (Introduced species)

Size: up to 4 cm (1.5 in)

Shape: elongate, triangular, inflated

Color: highly variable, usually white or cream-colored

Additional features: sharply angled ridge from beak to posterior end; sharply rounded dorsal end; hooked and pointed beak; attach to hard or soft substrate