UNIONIDAE IN THE CUYAHOGA RIVER: AN UPDATE ON POPULATION HEALTH

RACHEL ANDRIKANICH

Bachelor of Science

Cleveland State University

June 2014

submitted in partial fulfillment of the requirements for the degree

MASTER OF BIOLOGY

at the

CLEVELAND STATE UNIVERSITY

December 2020

We hereby approve this thesis for

RACHEL ANDRIKANICH

Candidate for the Master of Science in Biology degree for the

Department of Biology

and the CLEVELAND STATE UNIVERSITY

College of Graduate Studies

Thesis Chairperson, Dr. Robert Krebs

Department & Date

Thesis Committee Member, Dr. Bernard Walton

Department & Date

Thesis Committee Member, Dr. Emily Rauschert

Department & Date

Student's Date of Defense: June 7, 2019

DEDICATION

The completion of this thesis has been one of the most incredible and taxing experiences of my life. I would like to dedicate this work to those individuals that have both inspired and supported me during this journey. First, I would like to thank my family. To my parents I love you, you have listened to hours of mussel information without too much complaint and have supported me, even when that meant lighting a fire under me to complete my work. I would also like to dedicate this work to my siblings: Sara, Chris, and Becca who have been my biggest cheerleaders and allowed me to vent and laugh throughout the completion of my study. I love you and cannot wait to see you all soon!

I would like to dedicate this thesis to my boyfriend, Michael Greenland. You have been a great deal of support for the past six years, helped me continue my education, and encouraged me to finish my thesis. Thank you for letting me practice my defense in the middle of the night, repeatedly. I love you.

To Dr. Robert Krebs and my committee members Dr. Walton and Dr. Rauschert, this thesis is also dedicated to you. Your constant encouragement and dedication to my success is overwhelming. I could not have done this without any of you. I am so lucky to have known you and worked with you in this capacity. I cannot begin to thank you enough. I will miss you all terribly and have come to consider you as so much more than committee members. Thank You.

Finally, a thank you to my inspiration in life. Mr. Hoots and the Pig, especially Mr. Hoots and the Pig.

ACKNOWLEDGMENTS

The author wishes to express their sincerest thanks and appreciation to a great deal of people, without which this study would not have been possible. First, I would like to thank Dr. Robert Krebs, whose tutelage and expertise has been invaluable, both to my academic success and my personal growth. I would also like to acknowledge Dr. Emily Rauschert, whose insight and patience with me while I muddled through statistics has made me a better student of science and has allowed me to understand aspects of my own study in a more meaningful way. Next, I would like to acknowledge the contributions of Dr. Mike Walton, whose insight of study design is nothing short of genius. Working with Dr. Krebs, Dr. Rauschert, and Dr. Walton has been the highlight of my academic career, I could not ask for a better committee and I truly could not have done this without all of you.

I would be remiss if I did not acknowledge the inspiration for this study provided by Dr. Martin Huehner and Dr. Michael Hoggarth, as their previous research provided the framework for this current study. I also need to acknowledge the contributions and cooperation of the Geauga County, Summit County, the CVNP, and Camp HI for providing access and resources needed to successfully survey the Cuyahoga River. I would also like to acknowledge the contributions of Nikko Hoyga, Ryan Trimbath, Stephanie Sredinawa, and Jean Dykyj all who have accompanied me into the field and provided both professional assistance and some great times while collecting and measuring unionids. Finally, I would like to think Jared Blackstone, who has been invaluable to getting this manuscript ready.

UNIONIDAE IN THE CUYAHOGA RIVER: UPDATE ON POPULATION HEALTH

RACHEL ANDRIKANICH

ABSTRACT

Inspiration for the Clean Water Act (1972), the Cuyahoga River has been one of the most protected rivers in the country since the 1970s. Water quality is now within acceptable limits outlined by the Ohio Environmental Protection Agency, shoreline integrity has improved, and sediments mostly test free from toxins and heavy metals. With recovery, various faunal communities, such as freshwater mussels (family Unionidae), are expected to re-establish; no previous surveys of the Cuyahoga focus on this issue.

To better understand whether mussel populations recovered as water quality improved within the Cuyahoga Watershed, surveys were completed by two-person teams for one hour each. Sites were selected to compare either with earlier surveys in the 1990s within the Upper Cuyahoga or with possible dam removal sites within the Middle and Lower regions of the River. Site choice depended upon access.

Surveys of in 2012 were consistent with trends observed in the 1990s in species richness and population size within the upper portions of the Cuyahoga. However, when resurveyed in 2016 at the same sites, both abundance and species richness declined even in generalist species, as live individuals counted declined from 389 to 111. Species richness declined from the original eight species to four found in the 2012 survey. No previous work existed to provide comparison to our 2015 survey of 20 sites. In all, only 37 live individuals, representing three species, were located. One live individual was located within the Lower Cuyahoga in 2016, after teams surveyed 15 sites, representing a significant decline in abundance and diversity as the Cuyahoga flows from Geauga County, Ohio to the Cuyahoga Valley National Park and into Lake Erie.

The loss of freshwater mussels is a complex problem resulting from the building and release of impoundments, pollution, and flow dynamics, challenging the ability to isolate a single cause. Removal of dams has increased complexity of this problem in the lower portions of the river. As continued decline is expected, further work must be completed to understand how to restore this imperiled fauna.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Introduction

Mussels in the family Unionidae comprise a diverse group of pseudo-sessile bivalve mollusks found throughout aquatic ecosystems. Currently, 837 species are recognized (Graf & Cummings, 2007), and taxonomic classifications continue to be heavily debated. Species morphology varies considerably among unionid mussels, though most species of unionids measure 3-25 cm at maturity (Watters et al., 2009). Environmental factors, including sediment type, dissolved oxygen levels, and nutrient availability, contribute to other morphological traits such as coloration and body shape (Graf & Cummings, 2007). Unionid mussels in suitable ecosystems are often long-lived, exceeding 25 years.

Globally they are most common in permanent freshwater systems in low to moderate altitudes, as higher altitude systems lack necessary fish and nutrients required by the family Unionidae for survival (Watters et al., 2009). Unionids are prevalent throughout the Northern Hemisphere, and they have thrived in freshwater ecosystems within North America, especially east of the Rocky Mountains (Watters et al., 2009). Unionid mussels are more diverse and abundant within the waters of the United States than any other country in the world, boasting approximately 292 individual species 30 years ago (Turgeon et al., 1988). In recent years, however, the species richness and abundance of unionid mussel assemblages have declined at alarming rates, with two-thirds of these species presumed extinct, imperiled, or vulnerable (Stein & Flack, 1997). This proportion makes unionid mussels the most threatened large family of animals on the planet (Stein & Flack, 1997). To compound this problem, many species of unionid mussels are considered functionally extinct, a phenomenon that occurs when a group of animals is present but no longer able to reproduce at sustainable abundance (Bogan, 1993).

This great decline is unlikely to result from a single factor: A variety of causes appear to create unsuitable habitat for the Unionidae, including anthropogenic disturbance, water fouling, inbreeding depression, competition, and host fish loss. It is challenging to understand the impacts of each of these factors, as they are difficult to study in isolation. Many factors are interrelated and vary in severity seasonally, geographically, and in the degree of anthropogenic interference. This introduction focuses both on the ecosystem services provided by unionid mussels and on the various environmental threats facing this imperiled fauna.

Ecosystem Services Provided by Unionid Mussels in Freshwater Systems

Unionid mussels provide a wide array of ecosystem services (Vaughn, 2017), including offering ecological advantages to freshwater systems as well as social and economic opportunities for humans. The breadth of these services increases with mussel abundance and decreases with extirpation. The Unionidae are robust filter feeders that aid in nutrient cycling in the water column and in interstitial spaces within the sediment

(Vaughn, 2017). They filter water for nutrients and consume bacteria, algae, and phytoplankton (Vaughn et al., 2004). As a result, areas dense in individuals have lower rates of biofouling and significant reductions in toxins harmful to humans, especially microcystins (Nicklin & Balas, 2007).

Unionid mussels also contribute to the reduction of inorganic material and pollutants throughout the water column (Vaughn et al., 2004). Calcium carbonate, phosphorus, and nitrogen are often sequestered in the tissues of the mussel for growth, repair, shell formation, and reproduction (Vaughn, 2017). Death within mussel assemblages also has the capacity to create large amounts of inorganic influx into the substrate of freshwater systems, as the decomposition of mussel valves release these materials back into the water column (Vaughn et al., 2004).

Unionid mussels perform diverse roles in aquatic food webs, with each life stage of the Unionidae possessing unique predators (Vaughn, 2017). Juvenile unionid mussels are consumed primarily by fish species including pumpkin-seed fish, freshwater drum, and short-nosed sturgeon (Smith, 2001). Adult unionid mussels are prey for a variety of faunal groups, including birds, muskrats, river otters, mink, racoons and larger fish species such as Lake sturgeon (Watters et al., 2009). Mammalian predators will eat multiple mussels in each locale, forming piles of valves referred to as middens near the entrances of their respective dens (Owen et al., 2011). These middens, composed of decomposing valves, create a type of slow-release fertilizer in shoreline ecosystems, providing a nutritional breeding ground for insect species and allowing for reproductive opportunities for terrestrial organisms (Vaughn, 2017).

Mussel assemblages produce nutrients for algae and phytoplankton communities by expelling nitrogen- and phosphorus-rich inorganic molecules as a result of catabolism as feces or pseudofeces (Nicklin & Balas, 2007; Vaughn et al., 2004). An influx of primary producers increases food resources for fish, insects, and other macroinvertebrates (Howard & Cuffey, 2006), sustaining increased species diversity throughout the entire aquatic ecosystem (Vaughn et al., 2004). Aquatic systems boasting higher numbers of unionid mussels often contain higher levels of bacteria and phytoplankton, as nutrients expelled from unionids create approximately 40% of the nutrient requirements for these microbes (Vaughn, 2017).

With such a variety of ecosystem services provided by unionids, decreases in abundance can be problematic for freshwater systems throughout the United States (Vaughn, 2017). Additionally, study of the reasons of decline can be difficult, as they often interoperate to create many multifaceted issues. However, the main contributors of unionid decline can be categorized as issues with impoundments, competition, and environmental pollution.

Impoundment and the Unionidae

Dams throughout the United States have been constructed for hundreds of years for a variety of social and economic reasons. Many communities receive their drinking water from reservoirs, and dams help mitigate flooding throughout areas downstream of rivers and large streams. Moreover, many communities and businesses receive power from hydroelectric plants. Although beneficial to human populations in the short-term, the changes made to these watersheds can be catastrophic to native mussel fauna.

The number of dams throughout the watersheds of the United States is estimated at approximately 80,000, although this estimate only includes dams taller than 7 meters (U.S. Geological Survey [USGS], 2005). The impact of smaller dams on river health is more difficult to assess, as approximately 90% of these dams are privately owned or are found in water with little access (Singer & Gangloff, 2011). Throughout North America, it is estimated that as few as 40 rivers remain without any man-made dams or impoundments (Benke, 1990).

When dams are constructed, a lacustrine environment is created where water was previously free-flowing. Most species acclimated to flowing water are unable to survive in the greatly stilled water created by dams. If mortality does not occur from the sudden change in flow dynamics, populations in impounded areas become affected by the increased prominence of suspended solids in the water column. For most species of unionid mussels, inpoundments are detrimental to metabolic rates and interfere with their ability to filter feed properly (Watters, 1996), as the lacustrine environment changes planktonic food supply and may clog incurrent and excurrent siphons (Sethi et al., 2004). Increased sedimentation hinders recruitment of shell components, especially calcium carbonate (Vaughn & Taylor, 1999), and Unionidae to have more difficulty successfully secreting and maintaining shell layers.

Fish assemblages also struggle to be sustained in the transformation between lotic and lacustrine systems. Unionid mussels rely on host fish to successfully complete their life cycle, and therefore the fitness of fish populations is paramount. The presence of host fish within a watershed can account for approximately 44% of the variation in unionid mussel assemblages of the same area when environmental variables are similar (Schwalb et al., 2013).

Many species of freshwater fish are disappearing at a rate almost as alarming as the Unionidae: Recent reports estimate that approximately 39% of freshwater fish species known in North America are currently in serious decline or extinct (Jelks et al., 2008). Almost 75% of North American freshwater fish decline may be caused by physically altering habitat (Richter et al., 1997). When dams are erected, fish must reside within the geographical boundaries created by these impoundments, often restricting access to suitable habitat for spawning and decreasing interaction with unionids (Watters, 1996).

Dams also create numerous alterations to the hydrology within mussel habitat. Water collected behind dams reduces the prevalence of the Unionidae to the shallow water ecosystems to which many are accustomed (Watters, 1996). Shallow water habitat is necessary for the phytoplankton, a primary food source for most species of Unionidae (Ricciardi et al., 1998).

Areas downstream of dams display profound and unpredictable increases or decreases in water temperature of up to 5 degrees Celsius (Singer & Gangloff, 2011), the effects of which can be observed up to 25 miles downstream of even small dams (Maheu et al., 2016). Flux in water temperature often stresses the thermal tolerance limits (TRLs) of both unionid mussels and their corresponding host fish (Singer & Gangloff, 2011). When the TRLs of these animals are stressed at the irregular intervals associated with dam regulation, especially dams that impart a cold hypolimnetic release, common to many reservoir dams, mussel populations may become sterile in downstream areas. Moreover, larger adults may survive for years, masking species decline (Maheu et al., 2016).

Dams concurrently diminish the ability of native mussel populations to remain contiguous and form larger communities, fragmenting larger assemblages. This discontinuous distribution creates increased levels of genetic homogenization and constricts the ability to recruit genetic diversity, contributing to inbreeding depression, although trouble rearing mussels in laboratory conditions has left gaps in the understanding of potential long-term consequences. What is understood, however, is that discontinuous unionid populations limits local adaptation, which is detrimental in combatting disease (Watters, 1996).

Studies previously completed on dams and the Unionidae suggest that an association between dam size and the health of the overall Unionid population: the larger the dam, the more adverse the effects (Gangloff et al., 2011). With the severe and varied complications dams create for freshwater biota, it is imperative to most wildlife management teams to restore freshwater systems to natural conditions (Watters, 1996). Though admirable in purpose, dam removals create complex and interrelated issues of their own.

Short-Term Issues of Dam Removal

When dams are removed, substantial amounts of sediment are released from behind the impoundment, lowering water levels considerably throughout the area. When this occurs often, extant mussel assemblages are exposed to air, and desiccation can occur. Even if desiccation is avoided, populations are exposed to elevated water temperatures and flux in dissolved oxygen levels (Maheu et al., 2016). Mortality rates as high as 95% have been observed in watersheds after dams are removed (Cope et al., 2003).

Dam removal may also inadvertently pollute the watershed (Doyle et al., 2003). One famous example of this phenomenon was the Edwards Dam on the Hudson River. When this dam was removed in 1973, substantial amounts of pollutants, including oil runoff and polychlorinated biphenyls (PCBs), filled the downstream areas after release from the polluted reservoir and devastated faunal breeding grounds. The increase in sedimentation also altered flow patterns, and the now heavily polluted water was unable to freely flow down the river, causing large patches of toxic still-water. It was not until the Edwards community instituted a costly clean-up effort that the problem was mitigated (Doyle et al., 2003).

Supersaturation of the oxygen in water is another problem for the Unionidae and host fish (Doyle et al., 2003). The sudden increase in pressure and velocity directly following dam removal increases dissolved oxygen levels, creating more dissolved oxygen (> 100%) than the water can normally accommodate. Thus, dam removal increase chances for fish to contract gas-bubble disease, an acute condition that can occur rapidly when fish filter supersaturated water through their gills. The increased oxygen leaves the bloodstream, creating bubbles around the gills, eyes and swim bladder (Rodeles et al., 2017), which is can be fatal for fish in a short time (Rodeles et al., 2017) and detrimental to unionid reproduction (Tuckerman, 2006).

Long-Term Issues of Dam Removal

Long-term effects of dam removal are far less understood than short-term effects, for which monitoring is often mandated as part of many restoration projects (Bednarek & Hart, 2005; Foley et al., 2017). Changes in river flow regime are the best understood consequences of dam removal. After several weeks, regulation of water flow rates is often less dynamic than in impounded watersheds (Bednarek & Hart, 2005; Major et al., 2017). Without humans periodically releasing water downstream, the downstream biota are less subjected to damaging influxes of water and the release of suspended sediments as reservoir maintenance occurs (Doyle et al., 2003). In response to the less regulated water flow, downstream biota often become more abundant and diverse than are flora and fauna associated with impoundments, though recovery is often slow (Bednarek & Hart, 2005).

However, not all effects of dam removal are positive. Various unionid mussels, such as *L. siliquoidea, L. fragilis*, and *L. complanata* species, were extirpated with the removal of a dam in the Illinois River in the early 1900s (Tiemann et al., 2016). It was not until the early 1980s that the discernible recovery of any invertebrate species was recorded within the Illinois River downstream from where the dam was removed (Sietman et al., 2001). Recovery of extirpated unionid populations are heavily influenced both by the availability of source populations after the flood event following impoundment removal and by proximity to high quality host fish (Sethi et al., 2004).

Interspecific Competition

Dreissena Polymorpha

Dreissena polymorpha, or zebra mussels, became a main competitor of the Unionidae in many lentic systems within the United States. Zebra mussels are small relative to unionid species, with average size not exceeding 50 mm (Schloesser et al., 1997). Zebra mussels, as well as another dressinid invader *Dreissena rostriformis bugensis*, or quagga mussel, were likely introduced from Northern Europe in the mid 1980s through contaminated shipping ballast (McMahon, 1996). Their numbers have since exploded through the freshwater systems of the United States. It is estimated that there are more than

200,000 dressinid mussels per square meter throughout the Great Lakes (Gillis & Mackie, 1994), and countless numbers of dressinid mussels now inhabit the waters of the Mississippi, Ohio, Illinois, and Hudson Rivers (McMahon, 1996).

Dreissena polymorpha and *D. rostriformis bugensis* share habitat preferences (Quinn et al., 2013) and compete directly with unionid mussels for nutrients in a variety of ways. Dressinid abundance depletes the water of nutrients available for unionid mussels, as dressinids are exponentially more abundant than unionids (Mackie & Schloesser, 1996). Secondly, juvenile dressinids grow easily on the hard substrate of adult unionids and drastically interfere with the ability of the unionids to obtain nutrients from the water (Schloesser et al., 1997). *Dreissena polymorpha* and *D. bugensis* outcompete all species of unionid mussels throughout the United States (Ricciardi et al., 1998), especially within large rivers like the Ohio, Mississippi, and Illinois and within all Great Lakes (Dzierżyńska-Białończyk et al., 2018; Schloesser et al., 1997).

Zebra and quagga mussels attach themselves near the incurrent and excurrent siphons of the unionids using thread-like structures referred to as byssal threads; sometimes these dressinids number in the thousands. One study counted over 10,000 zebra mussels attached to one unionid host (Gillis & Mackie, 1994). Once attached, the byssal threads of attached dressinids act like anchors, which makes it very difficult for unionid mussels to detach themselves from these parasites (Dzierżyńska-Białończyk et al., 2018). Zebra mussels then feed on the nutrients obtained near the siphons of the Unionidae. Zebra mussels that colonize a unionid often outweigh their host by an average of fourfold, though an eightfold increase in weight has been observed, especially earlier in the colonization period (Schloesser et al. 1997).

Quagga Mussels

Quagga mussels also parasitize unionids; however, parasitic activity is much less successful, as byssal threads within this species are often weaker and more brittle (Peyer et al., 2009), resulting in anchoring that is easily disrupted by the unionids. Byssal threads within quagga mussel species are also slower to attach and less rigid, creating a decreased number of successful anchoring events (Karatayev et al., 2014)

Unionid mussels that are parasitized often have physical abnormalities that affect their valves and interferes with the shell's ability to close completely (Schloesser et al., 1997; Strayer & Malcom, 2018). The inability to completely close their valves interferes with the burrowing capabilities of unionids, making it virtually impossible for unionids to find shelter when water conditions become unfavorable (McMahon, 1996; Strayer & Malcom, 2018).

Dressinid assemblages excrete large amounts of waste material (Mackie, 1991). The fecal matter of the abundant zebra mussel creates intolerable water conditions for endemic unionid mussel populations. Colonies of dressinids create such a poor benthic environment that unionid mussel assembleges often die of anoxia, a condition created when adequate oxygen is unable to reach tissue (Gillis & Mackie, 1994).

Successful invasion of *D. polymorpha* into the watersheds of North America is further explained by higher tolerance levels expressed within populations of zebra mussel. *D. polymorpha* can establish populations in a wider range of habitats than even the generalist species of the Unionidae, such as *P. grandis* and *L. siliquoidea*. Thermal tolerances of zebra mussels are often greater in range than those of unionid mussels. In laboratory conditions, *D. polymorpha* possesses thermal tolerances at an average of +/- 5°C wider than generalist species of the Unionidae, including both *P.grandis* and *L. siliquoidea* (Mackie,1991; McMahon, 2015). This allows zebra mussels to grow and reproduce in a wider range of aquatic environments. Moreover, the thermal regime of *D. polymorpha* allows zebra mussels to continue to filter water and reproduce even when environmental cues suppress those behaviors within the Unionidae (Gillis & Mackie, 1994). As their large populations filter water indiscriminately, irrespective of temperature cues, *D. polymorpha* exhibit higher tolerances to environmental stressors, such as pollutants and heavy metal toxicity, than do their unionid counterparts (Ricciardi et al., 1998).

Calcium, necessary for shell growth and fortification, is required in far lower quantities in *D. polymorpha* (approximately 40 mg/L) than is required by most unionid mussels (approximately 50 mg/L; Gillis & Mackie, 1994). As anthropogenic remediation efforts mitigate centuries of pollution, calcium levels within the Great Lakes have decreased from approximately 60 mg/L to 35.7 mg/L within Lake Erie and 39.9 mg/L in Lake Ontario (Cohen & Weinstein, 2001). As calcium levels are anticipated to decline further, the discrepancy in calcium requirements between unionids and zebra mussels may become increasingly important.

Anthropogenic disturbances, such as damming, also do not limit dressinid populations, as these species thrive in slow moving water. Moreover, unlike unionid mussels, they do not require host fish to complete their metamorphoses from larvae to adulthood, instead relying primarily on water current and boat movement for dispersal, provided currents are slow-moving (Ricciardi, 1998). It is estimated that, once zebra mussels invade a unionid habitat, the population of unionid mussels is extirpated within 4-8 years (Ricciardi, 1998). Moreover, it is believed that the introduction of zebra mussels into the home range of endemic unionid mussels increases the likelihood of native mussel extinction tenfold (Ricciardi et al., 1998).

Asian Clams

In addition to *D. polymorpha*, native Unionidae must also compete with another bivalve invader, the Asian clam, *Corbicula fluminea*. Smaller than most native unionids, they do not typically exceed 50 mm and are brown and yellow in color (Pigneur et al., 2014). Introduced to the Western United States from Asia as a food source in the mid 1930s (Pigneur et al., 2014), Asian clam populations spread easily and have been found throughout the United States.

Corbicula fluminea is hermaphroditic, and one individual can create populations over 100,000 individuals in one year (USGS, 2005). This productivity allows rapid colonization of a variety of watersheds, and *C. fluminea* can thus overtake unionid mussel populations in much the same way as dressinid mussels. Asian clam populations are so numerous that they can often exceed 10,000 individuals per square meter (Pigneur et al., 2014). This population density is catastrophic for native mussel fauna, as unionids are unable to sequester nutrients or filter effectively as *C. fluminea* (French & Schloesser, 1996). According to laboratory studies, each Asian clam can filter as much as 1370 ml/hr/individual compared to a filtration rate of approximately 490 ml/hr/individual for unionids (Lauritsen, 1986)

Unlike *D. polymorpha* and the Unionidae, however, *C. fluminea* is considerably less tolerant of environmental variability. Colonies of Asian clams are prone to massive extirpation events (Scheller, 1997) when shifts in temperature or pH occur (Pigneur et al., 2014). Mortality rates for both the Unionidae and Asian clam are positively correlated with the density of Asian clams within a watershed. As *C. fluminea* decompose, ammonia levels within the freshwater system increase (Scheller, 1997). As ammonia levels increase, dissolved oxygen levels decrease, creating an ever more anoxic environment for extant unionid populations (Scheller, 1997).

Environmental Pollution and Unionid Decline

Dissolved oxygen, pollutants such as ammonia, and heavy metal toxicity comprise another set of interrelated environmental stressors placed on the Unionidae, as communities in freshwater systems located within industrial, commercial, or agricultural lands experience higher levels of exposure to environmental contaminants (Nickel et al., 2019). These types of land usage introduce many pollutants into the water column and sediment through runoff and waste materials (Nickel et al., 2019; Villella et al., 2004). Increases in sedimentation often occur in these areas, which lead to an increase in the amounts of sediment and contaminants within the substrate (Diamond et al., 2002; Prochazka et al., 2017). Sedimentation influx from industrial and agricultural endeavors also may make the sediment less porous for unionids, creating difficulty for burrowing and movement as the sediment becomes increasingly harder to manipulate (Sparks & Strayer, 1998). Fertilizers also can destroy mussel populations.

Often, mussel assemblages located within highly developed land experience habitat destruction. According to Diamond et al. (2002) and Nobles and Zhang (2011), anthropogenic disturbance is positively associated with levels of hydrologic regime alteration. Additionally, there is a positive correlation between increased incidences of shoreline disturbances and degradation and unionid decline (Diamond et al., 2002), which complicates unionid survival. In addition to the impact of thermal pollution on unionid assemblages, mussels are affected by inhabitation near pollution sources. Proximity to pollution sources is paramount, as mussel assemblages located downstream from point source pollution experience more acute symptoms of pollution toxicity than do mussel assemblages located farther from point source pollution (Naimo, 1995). Unionids proximal to this pollution experience increased mortality as nutrient inputs, turbidity, and water levels are consistently in flux and as water temperatures consistently exceed most naturally occurring regime cycles (Villella et al., 2004).

Commercial and industrial entities greatly affect water temperature, causing a phenomenon known as thermal pollution. Most thermal pollution is caused by an extreme rise in temperatures at the point of industrial or commercial discharge (Bobat, 2015). This substantial increase in temperature affects levels of dissolved oxygen within the water as well as above normal growth of algal blooms and harmful bacterial colonies (Vaughn & Taylor, 1999). Moreover, temperature can compound the effects of the above environmental stressors, as an increase in temperature often corresponds with a more potent variation of most pollutants (Vaughn, 1999). The impact of these exposures on unionid mussels increases drastically with elevated water temperature and lower water levels (Viarengo & Canesi, 1991).

Dissolved Oxygen and Anoxia

Levels of dissolved oxygen are vital for mussel health. Lower levels affect larval and juvenile mussels most severely, ceasing recruitment (Sparks & Strayer, 1998). In adults, short-term exposure to anoxic environments slows growth rates and metabolic functions, causing various health and growth issues; exposure in excess of a few weeks and will often lead to death (United States Environmental Protection Agency [EPA], 2003).

Young mussels can tolerate anoxic conditions for only short periods of time and will perish in a few days if conditions persist (Vaughn & Taylor, 1999).

Behavioral changes prior to death have been observed in juvenile unionids in anoxic conditions, including opening of the valves and extension of the incurrent and excurrent siphons, making juveniles even more susceptible to predation and pollution in such conditions (Sparks & Strayer, 1998). Moreover, as habitat becomes anoxic, host fish species will avoid the area in which the affected mussel assemblage is located, making dispersal of glochidia impossible (Sparks & Strayer, 1998).

In 2000, the EPA reported that, although the levels of dissolved oxygen have risen to adequate levels (approximately 5-6 mg/L) within most freshwater systems in the previous decade, dissolved oxygen levels are still problematic around water treatment plants and in areas that experience low water flow (EPA, 2003). In addition to water treatment facilities, nitrogen and phosphorous found in fertilizers and other commercial chemicals can cause rapid growth of harmful algal blooms within the water, depleting oxygen and often creating anoxic conditions even in highly developed watersheds (Vaughn & Taylor, 1999).

Unionids and Ammonia

Exposure to ammonia, a nitrogenous byproduct of decomposition found most fertilizers and industrial chemicals, affects both young and adult unionids in varied ways (Newton, 2003). In laboratory experiments, ammonia sequestered in the mantle tissue of adult unionid mussel may register with concentrations as high as 127 µg NH3/L, levels lethal to adult mussels, like *P. grandis* and *L. siliquoidea*, after only a few days of exposure. Smaller concentrations of 93 µg NH3/L can be lethal to adult mussels after prolonged exposure of approximately 10 days (USGS, 2005). While not fatal, a concentration of approximately 31 μg NH3/L may prevent unionids, especially juveniles, from growing or sequestering materials at (Augspurger et al., 2003).

Currently, all three of these measurements fall into current legally acceptable levels for ammonia concentrations within the freshwater systems of the United States: The EPA requires that ammonia concentrations remain between 2.0 mg/L and 3.0 mg/L during the months of May through October; between 5.0 mg/L and 7.5 mg/L in March, April, and November; and between 8 mg/L and 12 mg/L in December, January, and February to meet CWA standards. As such, protective efforts for unionid mussels are relatively ineffective (USGS, 2005).

Heavy Metal Toxicity

Heavy metals such as cadmium, copper, and mercury are found in both the water column and upper layers of sediment. The distributions of these materials cause unionid mussels to sequester high levels of heavy metals following prolonged low level exposure (Naimo, 1995). Different areas of unionid anatomy bioaccumulate and retain compounds at different rates, with most sequestration occurring in the gills, kidney, and mantle (Besada et al., 2011).

Each metal affects mussels differently, causing disruptions in growth, physiological functions such as filtration and reproduction, and behavior (Naimo, 1995). Toxicity varies by species, with smaller species being more affected, and by surroundings, as point source pollution and warmer climates create higher incidences of toxicity (Besada et al., 2011). Heavy metals create biophysical abnormalities of both shape and functionality in the major organ systems in addition to degradation of valve shape integrity (Watters et al., 2009).

Copper is known to stay suspended in the water column and lowers the critical thermal maximum of adult mussels 2 °C in only two days at only 10 ppb. Quantities of copper at 25 ppb are lethal to adult mussels after prolonged or repeated exposure (Havlik & Marking, 1987). Copper is even more lethal for glochidia, as they are unable to sequester heavy metals within their tissue and have lower overall tolerance limits (Havlik & Marking, 1987). There is also at least circumstantial evidence that elevated copper levels within the water column and sediment create higher levels of susceptibility to disease in some mussel species by disrupting innate immunology (Parry & Pipe, 2004)

As a result of dam removal, competition, anthropogenic impact, and environmental pollution, the family Unionidae is experiencing decline throughout freshwater systems of the United States. These declines in abundance are illustrated by not only the rare or endangered species but also within even the populations of generalist mussels. With reduction in mussel assemblages,

Utilizing the Cuyahoga River in Northeast Ohio as a model to illustrate current Unionid health in small river systems, this project focused on the assemblage dynamics of the family Unionidae within this heritage river. Generalist species such as *Pyganadon grandis*, *Lampsilis siliquoidea,* and *Lasmigona complanata* were utilized to illustrate trends that threaten unionid species broadly while the state-endangered unionid, *Ligumia nasuta*, will reflect the decline witnessed within the specialist species. These mussels were selected, as they are common throughout numerous watersheds within the Central and Eastern United States and, although research is still emerging on what are causing catastrophic declines, comparisons can be made between conditions within the Cuyahoga River and impacts against these same mussels in other watersheds. Moreover, a more integrated approach to explaining unionids' persistent decline will be examined utilizing multiple surveys of my own work, historical data on the unionid mussels of the Cuyahoga River, and other environmental reports from the Ohio Environmental Protection Agency (OEPA) and the Northeast Ohio Regional Sewer District (NEORSD).

The next chapter will provide information on the Cuyahoga River, as knowledge of the study site is imperative to understanding mussel decline within this watershed. Then, Chapter 3 will provide detailed information on the methodological approach of the study. Subsequently, Chapter 4 will provide the raw data collected during surveys, as well as brief descriptions of context. The final portion of this project will be dedicated to the significance of unionid mussel decline to the overall health of the Cuyahoga watershed, as well as ways to mitigate the loss of the ecosystem services provided by this imperiled faunal group.

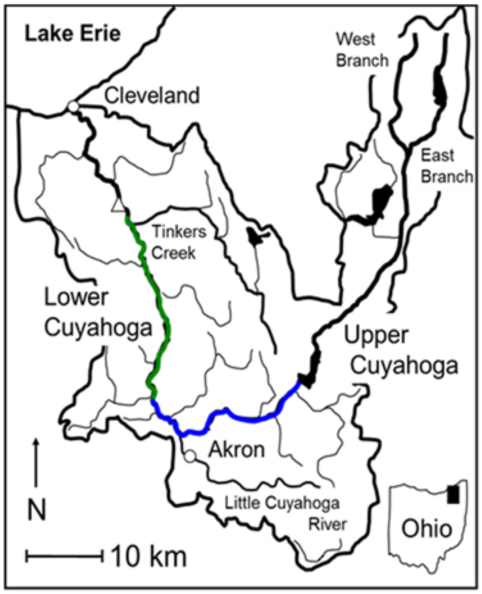
CHAPTER II

DESCRIPTION OF THE STUDY SETTING

The Cuyahoga River is 161 km long and begins in Geauga County, Ohio, only 70 km east of Cleveland proper, where the mouth opens at Lake Erie. The river flows southwest, entering Portage County, until the upper mainstem terminates at Lake Rockwell. Below a dam, the Middle Cuyahoga River forms a U shape around Akron and proceeds westward through Summit County before turning northward in Cuyahoga County. The Middle portion of the river ends at a gorge located in Cuyahoga Falls. The Lower Cuyahoga River includes the portion that flows through the Cuyahoga Valley National Park and Cleveland Metroparks, and northward to downtown Cleveland (OEPA, 2017). A map of the river appears in Figure 1.

Figure 1

Upper, Middle, and Lower Zones of the Cuyahoga River



The Cuyahoga River contains a fall line at the gorge that completely separates two distinct historical faunal group. The Upper and Middle Cuyahoga have also become separated by Lake Rockwell, which forms a distinct barrier to dispersal. As such, the faunal communities of the Lower Cuyahoga River are thought to be largely introduced through Lake Erie, not the Middle section of the Cuyahoga (Tevesz et al., 2002).

Each section of the river has unique characteristics. Within each zone, the Cuyahoga River has differing flow dynamics, sediment composition, topography, and surrounding land usage. As such, the designations into Upper, Middle, and Lower Cuyahoga River are maintained here to simplify and explain phenomena unique to each part of the Cuyahoga River.

Observations on Hydrology and Substrates within the Cuyahoga Watershed

The headwaters of the river are found within the Upper portion of the Cuyahoga river and are composed of the Eastern and Western Branches. The East Branch of the

Upper Cuyahoga River is approximately 7.5 meters wide at most points and generally shallow in comparison to the other portions of the West Branch. This part of the Cuyahoga River is comprised primarily of sand, silt, and clay, creating a sturdier substrate than is found in the Western Branch. The Eastern Branch possesses large pockets of detritus and fallen sticks throughout the sediment, creating the most variable substrate within the Cuyahoga River.

The West Branch of the Upper Cuyahoga is, on average, 4.5 meters wide and mostly marshland and softer muddy substrate, as compared to other portions of the Upper Cuyahoga River (Huehner, 1985). Water depth varies between approximately 1 meter in the upper portions of the Upper Cuyahoga river to approximately 3 meters around Hiram, Ohio during normal flows (Olive, 1975). It is near Hiram, Ohio that the Eastern and Western Branches converge and the mainstem of Cuyahoga River officially begins.

The mainstem of the Upper Cuyahoga River deepens, and as flow increases, sand is replaced by a rocky, clay substrate except for some riffles that become more common within this stretch of river than upstream. Riffles here often boast aquatic vegetation in stable, but not compact, sand. The Middle Cuyahoga River is often slower moving than the mainstem of the Upper Cuyahoga, and though typically shallower, it is interspersed with stretches of relatively deep water. Agriculture and residential housing is more prevalent along the shoreline, as fields often replace much of the forest present in the Upper Cuyahoga River.

The Lower Cuyahoga, which widens as it traverses the Cuyahoga Valley, is both the slowest moving and the shallowest portion of the river outside of the East Branch of the Upper Cuyahoga River. Sediment is composed mostly of pebbles and rock with intermittent sand bars. Aquatic vegetation is sparse when compared to the other portions of the Cuyahoga and is found primarily within the stretches of sand located among the rocky bottom (Watters, 1999).

Water Quality in Cuyahoga River

The OEPA, in conjunction with the NEORSD, has monitored the Cuyahoga River watershed since the implementation of the Clean Water Act in 1977, as it was this burning river that thrust the need for cleaner water criteria into national attention (EPA, 2017). In 2000, the OEPA surveyed over 100 sites along the Cuyahoga River for water quality, including chemical, physical, and biological integrity within the watershed. In 2000, the OEPA reported, for the first time in its history, that most (> 95%) of the Cuyahoga River and its tributaries exceeded established water quality standards.

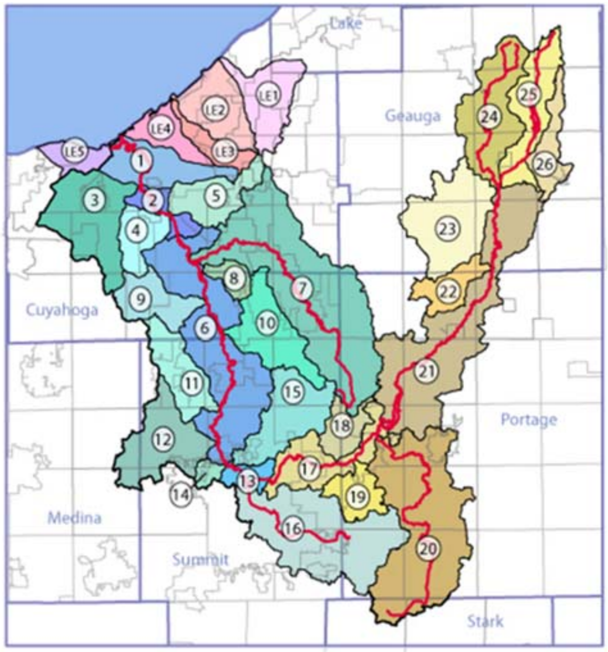
In studies completed in the upper portion of the Cuyahoga River, water conditions indicate slightly alkaline conditions, with an average pH of approximately 7.2 to 7.5 (EPA, 2017). This slight alkalinity is attributed primarily to forest runoff and sedimentation from shoreline habitat (Olive, 1975). As the shoreline possesses dense vegetation, decomposition rates of organic matter are higher than in other portions of the Cuyahoga (OEPA, 1999). In response to greater decomposition, ammonia levels within this portion of river are elevated, with average levels of approximately 0.9 to 2.1 mg/L (EPA, 2017). Within the same stretch of river, dissolved oxygen levels range from 10 to 14 mg/L (USGS, 2014).

Tributaries of the Cuyahoga River

There are approximately 26 tributaries known to contribute to the flow rate, water depth, and turbidity of the Cuyahoga River (Service et al., 2008). The largest, Tinkers Creek, enters within the Lower Cuyahoga and is responsible for over one-third of the water deposition in this stretch of the river (See Appendix Table 1). Changes in water depth, turbidity, shoreline morphology, and sedimentation rates in rivers are all positively correlated with the size of the contributing tributary (Benda et al., 2004), with some hydrological effects such as sedimentation and flow rates observed up to 25 km downstream of the confluence (Mosley, 1985). Figure 2 provides identification of all major tributaries for the Cuyahoga River.

Figure 2

Labelled Tributaries of the Cuyahoga River Watershed



In addition to contributing to the hydrology of the Cuyahoga River, tributaries also impact river fauna. Tributaries are important introduction pathways of fauna into larger freshwater systems, as they create important dispersal avenues between watersheds (White, 2007). Many fish species will spawn in smaller streams that act as tributaries for larger rivers. Once juvenile fish mature, they enter larger freshwater systems through the confluence and disperse downstream (White, 2007).

As fish populations spawn and disperse, so do the invertebrate faunal communities (Clay et al., 2015). Although less correlation is observed between tributaries and direct dispersal of arthropod and mollusk phyla, tributaries aid in dispersal by increasing the amount of suitable habitat through nutrient inputs and oxygen recycling (Clay et al., 2015). Macroinvertebrate communities are able to disperse farther in watersheds containing tributaries than within systems without well-defined tributaries (Mosley, 1985).

Land Usage of the Cuyahoga River Watershed

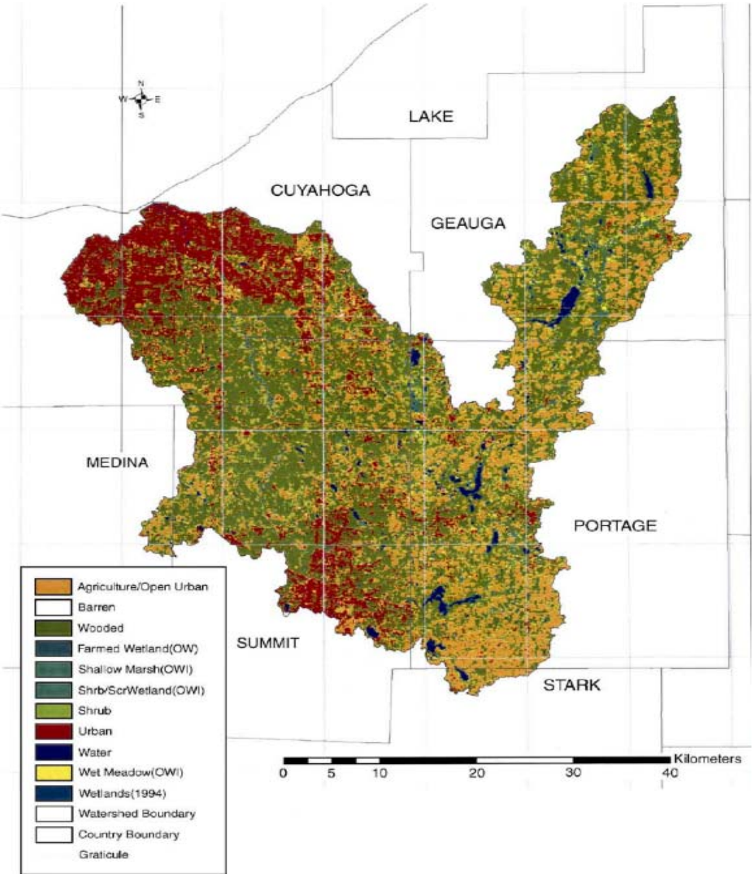
The Upper Cuyahoga River has a long history of agricultural use, beginning with the settlement of European settlers in the late 18th century (Dubelko, 2015), flourishing in the nineteenth century, and persisting today (USGS, 2005). Because of this history, sedimentation is problematic. Increased erosion rates, common with farm land, leads to higher levels of particulates within the water column, especially following storm events (Diamond et al., 2002).

As agricultural processes became industrialized, more fertilizers and pesticides were applied to crops that leach into the soil. With increased runoff associated with long term agricultural use, elevated levels of phosphorus and nitrogen, common in commercial fertilizers, are introduced into the watershed (Diamond et al., 2002) creating an environment ideal for rapid bacterial and algal growth (Zeitler, 2001). This exponential growth depletes available oxygen within the water column, creating anoxic habitat unsuitable for many floral and faunal groups.

When assessed in the latter portion of the 1960s, the Upper Cuyahoga faced an even more challenging problem to river health than increased agricultural pollutants: the impoundments created by Lake Rockwell, LaDue, and East Branch reservoirs (Zeitler, 2001). These impoundments service the areas around the mainstem of the Cuyahoga, providing drinking water to almost 200,000 people (U.S. Census Bureau, 2020). These reservoirs also reduce waterflow throughout this stretch of the river, which can reduce turbidity and dissolved oxygen in the water in downstream areas (Hornbach et al., 2014). Figure 3 below illustrates the differences in land usage amongst the three zones of the Cuyahoga River.

Figure 3

Land Usage in the Cuyahoga River Watershed (USGS, 2018)



Akron, Ohio, the fifth largest city in the state, flanks the Cuyahoga throughout the lower portions of the Upper Cuyahoga as well as much of the Middle Cuyahoga River.

Adjacent areas are part of the "Rust Belt" and possess a rich history of industry and heavy manufacturing (Teaford, 2017; Zeitler, 2001).

The development of the Rust Belt began in the middle of the 19th century. The area between Akron and Cleveland, Ohio was well known for the mining of copper and iron ore (Stradling & Stradling, 2008), from which waste materials were thrown indiscriminately into the middle and lower portions of the Cuyahoga River (Adler, 2002). These waste disposal practices created problems for residents who found the river polluted with foul odors and odd taste as early as the 1860s (Dubelko, 2015).

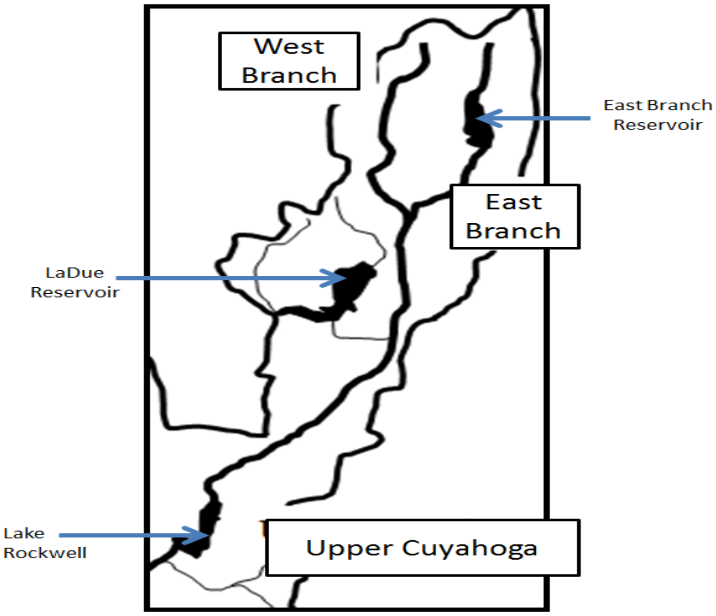
As the 20th century began, mining endeavors in this portion of the watershed were replaced with steel and paper mills and rubber factories (Adler, 2002). Waste from these industries were also released into the Cuyahoga River, creating a consistent influx of heavy metals, such as lead and iron, into the water and polluting both the water column and the sediment. The severity of pollution led Cleveland to build water intake tunnels 5 km out into Lake Erie (Dubelko, 2015). Other problems arose in this portion of the river, as these industries created thermal pollution downstream of industrial complexes, leaching the river of available oxygen. Although much of the industrial pollution has since been regulated within the area, regions of the Cuyahoga River are still recovering from the long history of industrial use (Dubelko, 2015).

Impoundments of the Cuyahoga River

Each zone of the Cuyahoga has impoundments, either manmade or naturally occurring, that impact the flow rates and water dynamics of the river. However, the Upper and Middle Cuyahoga have been subject to significant damming in the past. Any addition of impoundments (Figure 4) can affect water temperature and depth and reduce the heterogeneity of the river, which is important for unionid diversity (Maheu et al, 2016; Ries et al., 2016).

Figure 4

Impoundments of the Upper Cuyahoga River



Lake Rockwell

Lake Rockwell (41.1945, -81.3095) is the southernmost of the large impoundments. It is Lake Rockwell that creates the geographic barrier that defines the Upper Cuyahoga River. Completed in 1915, this large impoundment is not only the oldest of the three major reservoirs of the upper river (Ohio Department of Natural Resources [ODNR], 2017) but also the most protected. Lake Rockwell is Akron’s primary source of drinking water; thus, access to the public is strictly prohibited, as are recreational activities including fishing (City of Akron, 2016).

East Branch Reservoir

Completed in 1939, the East Branch Reservoir is the northernmost impoundment. Located in Geauga County, Ohio between OH-608 and OH-322, (41.3980, -73.5813), this reservoir is a secondary reservoir for the city of Akron, Ohio (ODNR, 2017). At 402 acres in size and at a maximum depth of 18 feet, the East Branch Reservoir regulates water flow through the Eastern Branch and the Cuyahoga River through cold water releases (ODNR, 2017).

LaDue Reservoir

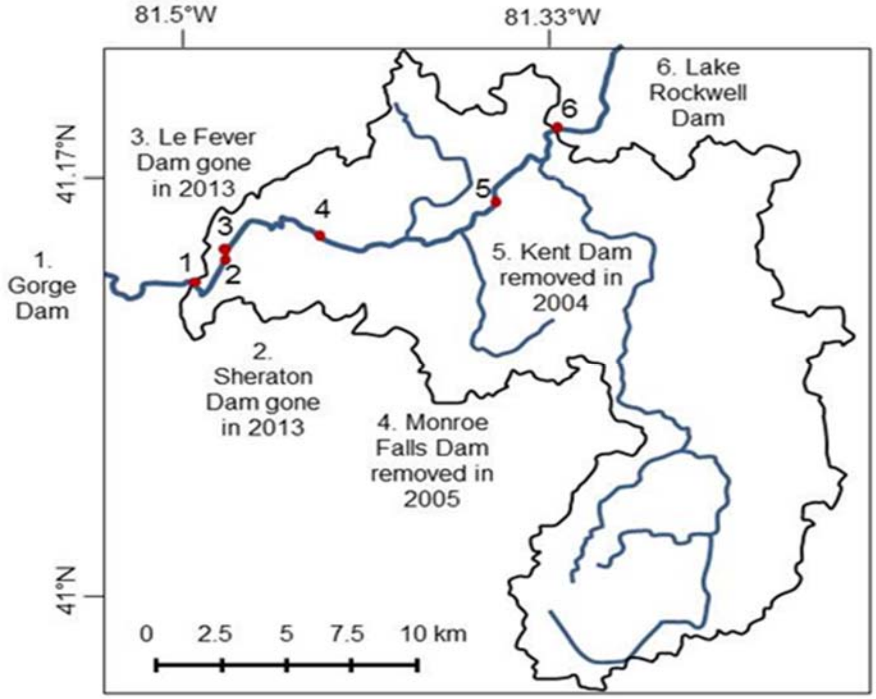
LaDue Reservoir, completed in 1963, is located south of the East Branch Reservoir in lower Geauga County, Ohio (41.3960,-81.1940; ODNR, 2017). LaDue Reservoir was created by damming Black Brook and Bridge Creek (City of Akron, 2016). Much like the East Branch Reservoir, this impoundment supplies water to Akron and contributes to water flow regulation of the Cuyahoga River (ODNR, 2017).

Impoundments of the Middle Cuyahoga River

Below Lake Rockwell runs the Middle Cuyahoga River (ODNR, 2017). When compared to the Upper Cuyahoga River, the Middle Cuyahoga boasts a more free-flowing naturally occurring watershed. However, this has not always been the case: Over the past 15 years, county and state officials associated with Summit, Portage, and Stark Counties removed four of six dams (Figure 5) that once heavily impacted the river (Appendices 2, 3, and 4; Mann et al., 2013).

Figure 5

Impoundments of the Middle Cuyahoga River



Although the Kent, Monroe Falls, Sheraton, and LeFevre Dams have been removed within the Middle Cuyahoga River, two extant dams remain. These two dams are the Rockwell and Gorge Dams. Rockwell Dam remains responsible for providing continuity in river flow within the middle stretch of the Cuyahoga (OEPA, 2000), releasing water as necessary during the summer months each year when water levels are typically at their lowest (OEPA, 2001).

The second impoundment is the Gorge Dam (41.0723, -81.2950). Built in 1912, the Gorge Dam stands 18 m tall. This dam was used primarily to power and provide cooling to an adjacent coal burning power plant (OEPA, 2001). Summit Metro Parks is currently looking to remove this dam to finish the restoration of naturally occurring water patterns within the Cuyahoga River; however, this dam will be more difficult to remove, as it is built amongst a large system of naturally occurring waterfalls (ODNR, 2017). This dam removal could cost upwards of 70 million dollars, more than the previous four dam removals combined (ODNR, 2017).

CHAPTER III

METHODOLOGICAL APPROACH

As the purpose of this study was to survey the entirety of the Cuyahoga River in order to update records on unionid abundance and diversity, each section of the river was surveyed in different field seasons. The Upper Cuyahoga River was surveyed both in 2012 and 2016. The Middle Cuyahoga River was surveyed in 2015, and the Lower Cuyahoga River, represented by the expansive stretch of river throughout Cuyahoga Valley National Park (CVNP), was surveyed in 2016.

All surveys within the Cuyahoga River were completed in a similar manner. Surveys at each site were accomplished by two researchers for one hour and included primarily visual and tactile surveys of the benthos. When water levels were low, as at most field sites, hands and feet were used to locate unionid mussels. When water was deeper but still traversable (> 1 meter), mussel rakes were used to dredge the sediment and locate mussel populations. Boats were also used as portable field stations in deeper water. Live mussels were measured, identified, and summarily returned to suitable habitat. Valves were collected by site and were catalogued in the lab after proper cleaning, and length was measured.

In addition to tactile surveys, shoreline surveys were completed to establish the presence of mussel fauna, both live animals and valves. These shoreline surveys were also employed to ascertain possible sites of point source pollution and to record issues with embankments. Surveyors were instructed to indicate evidence of shell middens in field notes. Water quality conditions were assessed using data from both the USGS and OEPA.

Shell size of the four most abundant mussel species within the Upper Cuyahoga were analyzed after both the 2012 and 2016 surveys. Variance within shell size was compared within each species to ascertain the presence of any generational differences and indicate reproductive events, as larger variance would indicate the presence of young and mature individuals. If variance were low amongst valves, it could indicate that individuals are roughly the same age, and thus multiple reproduction events have probably not occurred (Begley & Krebs, 2017).

Site Selection

The first consideration in site selection was shoreline access, both pedestrian and boat, when necessary. In addition, the various parks associated with each county played a critical role in survey decisions. Survey sites were included within both the Middle and Lower Cuyahoga River summited by and for Summit County and the surveys aided the CVNP to attain clearance for upcoming dam removal projects.

In 2012, 23 survey sites in the Upper Cuyahoga were selected based on the previous surveys of the same area completed by Martin K. Huehner (1985) and Michael Hoggarth (1990; Appendix B) and was funded by the Geauga Park Service. These sites were assessed for two main reasons. First, there was an extant record of these sites being suitable habitat for unionid mussels, which allows for an assessment of change in unionid survival. Second, when resurveyed in 2016, these sites would allow for a more accurate comparison of fluctuations in population abundance and species richness over the past 30 years. Updated information on unionid abundance and species richness could indicate whether water remediation efforts have been effective in stabilizing mussel communities since the mid 1980s. A table of sites selected for surveys can be found in Appendix A.

CHAPTER IV

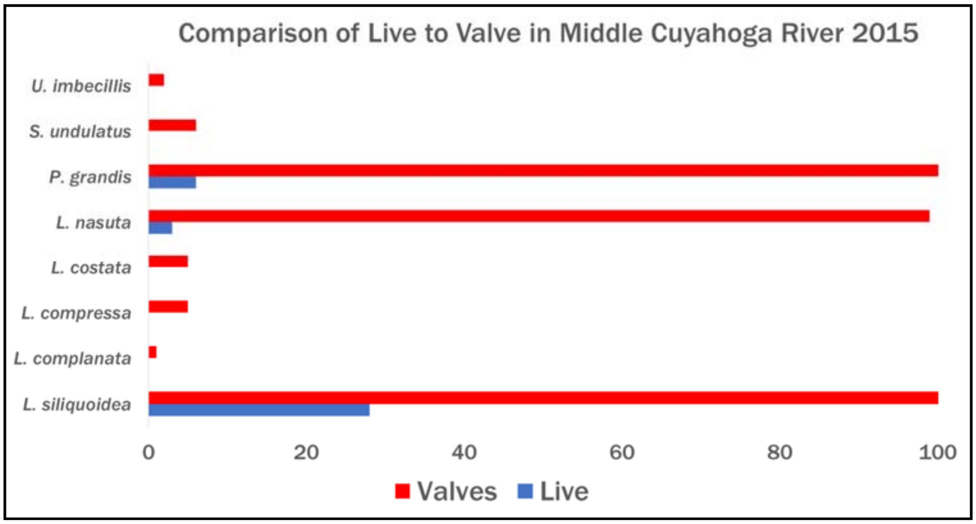
RESULTS

Middle Cuyahoga River

In 2015, 20 sites were selected for the survey of Middle Cuyahoga River. Given the absence of historical data on unionid mussel populations anywhere in the middle portion of the river, sites were selected at regular distances to ensure adequate sampling. Sites were also selected by the ability to establish clearly defined and easily accessible sites for future surveys of unionid mussel populations. Sites near Camp Hi, upstream of the Middle Cuyahoga, were also revisited during the 2015 survey to ensure that all parts of the river were surveyed and to establish congruence enabling comparison with data collected in 2012 (Appendix A). Live individuals were counted, as were valves. Results of the Middle Cuyahoga River survey are detailed in Figure 6 below.

Figure 6

Live Individuals and Valves of the Middle Cuyahoga River (2015)



The survey of the Middle Cuyahoga yielded 37 live individuals found from Lake Rockwell to the gorge in Cuyahoga Falls, Ohio, and unionid abundances were low throughout the majority of the survey. Only four species were represented throughout the Middle Cuyahoga River: *L. siliquoidea*, *L. nasuta*, and *P. grandis*. The most represented species was *L. siliquoidea*, with 28 (76%) of the individuals found belonging to this species. Six *P. grandis* representing 16% of the abundance and three *L. nasuta* were located, comprising the remaining 8% of mussels found.

Valves collected throughout this survey were numerous in comparison to live individuals, with 476 collected. In addition to being more abundant, valves collected throughout the Middle Cuyahoga illustrated greater diversity than did live individuals. Valves collected from Lake Rockwell to the Gorge were from eight species. Although diversity was higher amongst valves, the majority of these were from three species: *P. grandis*, *L. siliquoidea*, and *L. nasuta*.

Most (*n* = 225) of the valves were of *P. grandis*. This result may be explained by the sudden removal of four impoundments, which are known to cause regional extirpation as river conditions change from still water to free flowing. Similar circumstances could explain the relatively high numbers of valves of *L. siliquoidea* (*n* = 128) and *L. nasuta* (*n* = 99). However, causes of population decline are difficult to establish with certainty as no prior historical records of mussel health in this area exist.

Lower Cuyahoga River

As a survey for unionid mussel populations was desired by the CVNP prior to dam removal, sites of interest in the Lower Cuyahoga River pertained primarily to areas impacted by the dam. Other sites were set equal distance from one another beginning in the southern portions of the park and ending in the northern part of the CVNP. Sites were also selected considering access availability and to avoid a nest full of newly hatched bald eagles, *Haliaeetus leucocephalus* (see Appendix A).

One live *L. complanata* was discovered above the dam near Vaughn Road. This mussel was the first live mussel found in the region. This *L.complanata* was fully exposed and appeared unable to keep valves together, as the left valve would separate almost entirely from the right. Thus, the specimen exhibited greatly diminished health and was mistaken as fresh dead when first uncovered.

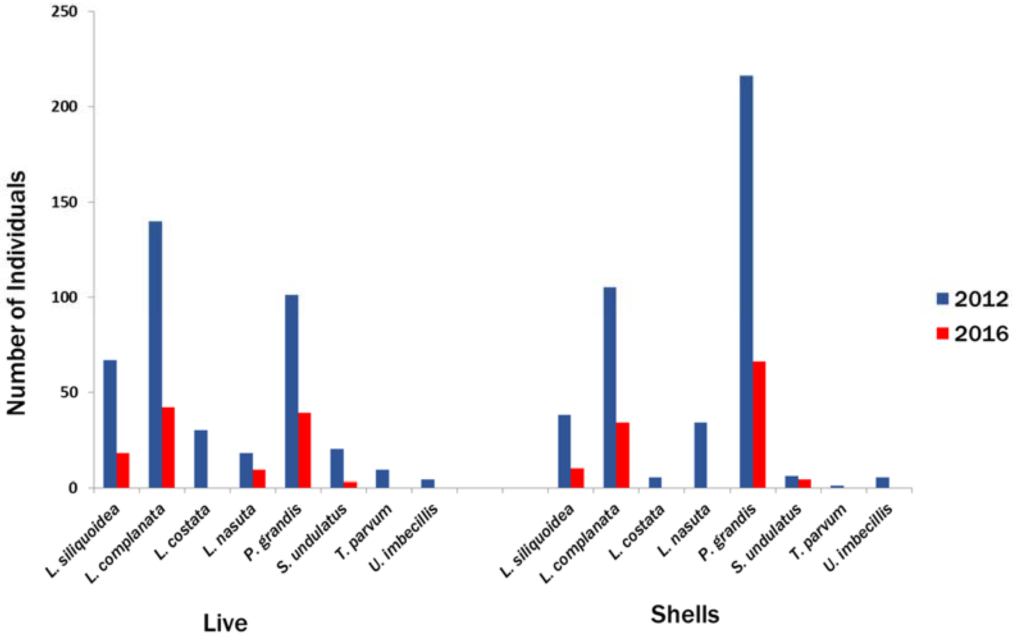
Within the Lower Cuyahoga River, the eight valves found represented three species*: L. complanata*, *F. flava*, and *L. siliquoidea*. The majority of valve were that of *L. complananta*, which comprised approximately 63% of valves found within the Lower Cuyahoga. Both *F. flava* and *L. siliquoidea* were located with one valve per species. No valves recovered were recently dead and all appeared to be subfossils, as the periostracum was highly degraded. As such, they offer poor indication of historic populations relevant to river health and provide little or no information as to where, or even when, these animals lived.

Upper Cuyahoga River

I surveyed the Upper Cuyahoga River twice, in 2012 and 2016. As stated previously, the sites selected for survey were established by a previous survey completed by Hoggarth (1990; Appendix B). As with the other surveys, live unionid mussels were counted and replaced in the river. Valves were collected, catalogued, and measured for variance. The number of live unionids and valves are displayed below in Figure 7.

Figure 7

Live and Valves in Upper Cuyahoga River (2012, 2016)



Note. No *A. ferussacianus* or *L. compressa* were found in either the 2012 or 2016 survey of the Upper Cuyahoga River. Exact numbers of live specimens and valves are listed in the Appendix.

Data indicate an approximate 1:1 ratio between live individuals and valves found, representing eight species. Most live specimens of Unionidae were found within the mainstem of the Upper Cuyahoga, with 56% of live individual abundance and seven out of the eight species represented. As the survey progressed farther upstream, both species diversity and abundance decreased. The West Branch of the Cuyahoga had three times the abundance of Unionidae as did the East Branch; however, it should be noted that only three of eight species were represented. The lowest abundance was present in the Eastern Branch, representing approximately 11% of the live specimens found; however, five of the eight species were found here. *P. grandis and L. complanata,* Giant Floater and White Heelsplitter, respectively, comprised the majority of live unionid mussels surveyed in the Upper Cuyahoga River watershed—approximately 62% of all live animals found. The other six species found were in lesser abundance with greater relative distances between discrete populations.

Valves located in the upper portion of the Cuyahoga indicate an opposite pattern when compared to live individuals found in the survey of the same areas. Most shells were collected within the Eastern and Western Branches of the Cuyahoga River, with the Western Branch containing the majority of valves, approximately 67%. The Eastern Branch represents approximately 18% of valves collected, and 16% of valves collected were located in the Main Branch of the Upper Cuyahoga River. Approximately 78% of valves collected in the Upper Cuyahoga River belonged to two species, *P. grandis* and *L. complanata*, mimicking the same pattern of abundance seen in the live individuals.

In 2016, sites of the Upper Cuyahoga were reexamined to gather comparative data for unionid health present then and at the time of the 2012 survey. Live individuals (n =

111) were located, signifying a 71% reduction in abundance from 2012 and a 76% abundance decline since Hoggarth's 1990 survey (Appendix B). The results also suggest that three unionid species are at risk for extirpation from the Upper Cuyahoga River: *A. ferussacianus*, *U. imbecillis*, and *T. parvum,* the latter two species being located during the 2012 survey. Common mussels, such as *P. grandis* and *L. complanate*, were noticeably sparse in number, while *L. siliquoidea* was absent from the historic habitat.

The mainstem of the Upper Cuyahoga contained 63 live individuals representing five species: *L. siliquoidea, L. complanata L. nasuta, P. grandis*, and *S. undulatus.* The Eastern pondmussel was noticeably harder to locate, with numbers drastically reduced when compared to the 2012 survey. When sites which previously had high abundances were re-examined, only one site near Hiram, OH contained any live *L. nasuta*.

In the West Branch, 47 live individuals were located, with the same three species represented in the 2012 survey: *L. siliquoidea, L. complanata,* and *P. grandis.* When the Eastern Branch was resurveyed, only one live *P. grandis* was located, representing the only live mussel found there. This discovery indicated the possible loss of four species within the Eastern Branch, as a population of 47 individuals had dwindled to one individual.

Variance of Valves within the Upper Cuyahoga (2012, 2016)

Valves from the Upper Cuyahoga were measured for size variation within species. Wider variation for valve length indicates some juvenile or younger individuals within the population. Then variance was compared between the surveys in 2012 and 2016 (Table 1).

Table 1

Variance of Valves found in the Upper Cuyahoga River

Species	Mean	*N*	Std Error	Range	Variance	Min	Max	Kurtosis	Skewness
L. complanata	14	71	0.386	13.4	10.6	5.1	18.5	0.215	-0.915
P. grandis	11.7	159	0.178	10.7	5.02	5.8	16.5	-0.582	0.061
L.nasuta	11.4	43	0.204	7.1	1.8	8.2	15.3	1.71	0.074
L. siliquoidea	10.2	58	0.285	9.5	4.72	5.1	14.6	-0.162	0.101

The greatest size variance of valves occurred within *L. complanata,* which suggests the presence of at least small populations of reproductively successful adults. Out of all the species analyzed, reproduction seems most probable within this group, as this species has had a rather recent introduction into the Cuyahoga. Additionally, *L. complanata* is the most pollution tolerant of the four species, meaning reproduction could be successful in this group when environmental conditions make it impossible in other unionid species.

The smallest amount of size variance was observed in *L. nasuta, L. nasuta* has maintained a diminished presence within the Upper Cuyahoga, making potential reproduction more difficult than in other species of unionid mussels within the same area. The Eastern pondmussel is also not as tolerant to pollution or temperature as are the other species examined. Even if adult *L. nasuta* continue to survive in the Upper Cuyahoga, it is unlikely that successful reproduction events are occurring.

The other species, *P.grandis* and *L. siliquoidea*, exhibited relatively low variability in valve length, making it improbable that these populations are having much reproductive success, especially as no young individuals were found alive. As these mussel species have always been abundant in the Upper Cuyahoga River, it is possible that the variance displayed is partly because, throughout the longevity of this species, reproduction was successful and thus a few smaller valves were located. These valves were often long dead and present a picture of historic reproductive success. However, as no smaller fresh dead valves were located in either the 2012 or 2016 survey, the likelihood of present successful reproduction events is minimal.

CHAPTER V

DISCUSSION

Mussel diversity and abundance is higher at the top of the watershed, within the Upper Cuyahoga River. Then, both mussel diversity and abundance declines in surveys that progressed farther downstream. Until almost no mussel diversity or abundance is observed within the Lower Cuyahoga River.

Middle Cuyahoga River

All live animals (*n* = 37) were found in deciduous forested areas, where canopy cover was at its densest (Hogya et al., 2016). The sites with the greatest mussel abundance were located near Kent, Ohio, and an abundance of live individuals was observed most often in eastern survey sites. As eastern sites are primarily associated with agricultural and forested areas, it follows that mussel communities would mimic those populations found in the Upper Cuyahoga River, which boasts the same land usage.

As the survey proceeded westward, abundance dwindled. Land usage shifts from agricultural and forested areas to urbanized and industrial areas towards Akron, Ohio. Live individuals were located in sites associated with higher levels of riparian zones. Areas with increased riparian zones tend to offer greater resistance against agricultural and commercial pollution and sediment degradation due to the abundance of vegetation within these areas (Morris & Corkum, 1996). In studies of habitat near riparian zones in smaller rivers, it was not uncommon for habitat to be dominated by a few main generalist species, especially *P. grandis* and *L. siliquoidea* (Morris & Corkum, 1996). Most of this abundance is explained in the tolerance limits of these generalist species to larger temperature and ammonia fluctuations also associated with riparian zones (Schwalb et al., 2013).

Notably, live individuals were often found partially or completely exposed on the river bottom. This is unusual for these species, which will often bury themselves, exposing only the siphons needed to filter feed. Burial like this is demonstrated in order to increase protection from predation and in response to temperature and toxin fluctuations within the water column (Watters et al., 2009). Observed departure from burying behavior may be explained as avoidance of contaminants released into the sediment with the removal of the dams throughout the Middle Cuyahoga River, as contaminants behind the impoundments would now be released downstream in large quantities (Sethi et al., 2004).

The Middle Cuyahoga historically possessed a series of impoundments—six dams, each over 3 meters in height (Tuckerman, 2006) With the construction of these numerous impoundments, mussel communities would have become increasingly more lentic, as the lotic mussel communities decreased after the construction of the dams.
As expected, valves located in the Middle Cuyahoga suggest a once-lotic community. Valves recovered within this survey indicates once present populations of *L. complanata* (*n* = 1)*, L. compressa* (*n* = 5)*, L. costata* (*n* = 5)*, S. undulatus* (*n* = 6)*,* and *U. imbecilis* (*n*

= 2), all of which are lotic species. Although abundance of these mussels was low, finding these valves reinforces the notion that lotic communities once existed in the area. Finding these valves could indicate small historic populations. However, sedimentation from the removal of the impoundments decreased the probability of locating numerous specimens.

The removal of the dams would have decimated established lentic populations. This was evidenced by the high number of both *P. grandis* and *L. complanata* valves located throughout the survey. As so many valves were found of these lentic species, populations were likely well established prior to dam removals.

With the removal of several impoundments, the Middle Cuyahoga River has been greatly restored to natural flow regimes, with increased heterogeneity throughout. River heterogeneity includes pockets of greater temperature variability, flow rate fluctuations, and increased variation in water depth, which allows for varied habitat suitable for a larger number of overall taxa. All of these restored conditions also reestablish the potential for successful reproductive events, as most unionid mussel species use environmental temperature cues to release gametes into the water column (Lefevre & Curtis, 1910).

Lower Cuyahoga River

In a previous survey of unionid populations throughout the CVNP, no live mussels were reported north of the 82 dam (Smith et al., 2002); however, one white heelsplitter was located in 2016, albeit in poor condition. As locating a live mussel above the dam was unexpected, it was remains apparent that unionid recovery is very poor within the Lower Cuyahoga River.

Upper Cuyahoga River

Site selection for the survey of the Upper Cuyahoga in 2012 was influenced by Hoggarth's survey in 1995 (Appendix B), and similar unionid mussel abundance and species richness between the two surveys was expected. Results indicated that both species diversity and richness in 2012 were similar to those found in the 1995 survey. For this reason, species abundance and richness in the 2016 survey were also expected to be similar to the 1995 and 2012 surveys. However, this new survey revealed that unionid mussel abundance and diversity had collapsed throughout the Upper Cuyahoga River. The Unionidae became overwhelmingly represented by only a few species—*L. siliquoidea, L. complanata*, and *P. grandis*—and no immature individuals of any species were located. Without the location of smaller individuals, it is expected that unionid reproductive events are largely unsuccessful in the upper portion of the river. With loss expected to continue within the these populations, probable causes of decline and extirpation were examined in the context of small river systems.

Probable Causes of Unionid Decline in the Cuyahoga River

Water and sediment quality was within full to fair attainment within all sites sampled for water quality in the Upper Cuyahoga with the exception of two sites around US 322 (EPA, 2000) in the West Branch. Although most pollutants of both organic and inorganic origins have been found within acceptable limits of federal and state regulations, there remains some concern over whether these attainments are sufficient for unionid health (Duncan et al., 2007). Throughout numerous studies of watersheds, values within EPA guidelines are actually outside the tolerance limits for various species of mussels. For instance, it is possible for amounts of heavy metal contaminants such as copper to be well within acceptable standards for the EPA but also far outside the tolerance limits for even a generalist species like *P. grandis*.

The gap that results may be troublesome for unionid health. For instance, from 2012 to 2014, copper levels in the Cuyahoga River exceeded *P. grandis* tolerance levels three times (USGS, 2014). Often, these values far exceed LC_{50} for adult *P. grandis* (15 to > 100 ug Cu/L; Wang et al., 2007). Adult mussels are not the only life stage affected by this level of copper in the water column, with an LC_{50} reported at approximately 7 to 86 ug Cu/L for glochidia and from 6.8 to 60 ug/L for juvenile mussels (Wang et al., 2007). Evidence suggests that exposure to copper levels lowers the LT_{50} of juvenile *L. siliquoidea* by 2 ºC in approximately 48 hours of exposure (Wang et al., 2007). To complicate this issue, copper has a unique chemical property that makes it largely unreactive in water. These unreactive copper ions may stay in the water column for longer than other compounds and do not settle out into the sediment like most heavy metal toxins (Parry & Pipe, 2004). As the EPA criterion for copper concentration is an average of 23 ug Cu/L at a hardness of 170 mg/L (OEPA, 2012), attaining this standard has negligible effect on the survivorship of young mussels and still creates problems for adult populations.

Impoundments

Impoundments also create obstacles for dispersal of unionid populations in the Cuyahoga. With the three large impoundments—LaDue Reservoir, East Branch Reservoir and Lake Roswell—dispersal becomes extremely unlikely west of Lake Rockwell. Host fish communities cannot navigate these impoundments, creating segregated populations of mussels above and below Lake Rockwell. These impoundments also have created a series of lentic environments in which species such as *P. grandis, L. nasuta*, and *U. imbecillis* survive while lotic species *like L. compressa, L. costata, S. undulates*, and *L. complanate*, which prefer quicker moving riffles and stronger currents, have reduced suitable habitat (Watters et al., 2009). The only exception is *L. siliquoidea*, which appear to survive equally as well in either type of environment. This fact may explain its abundance throughout the entirety of the upper and middle regions of the Cuyahoga River (Watters et al., 2009).

Ammonia

In addition, the persistence of these impoundments continues to keep levels of ammonia elevated, especially in the summer months when temperatures are highest. Ammonia levels are also highest in this stretch of the river, as much organic matter is in decay within the forested and agricultural land here. When observed in laboratory conditions, *P. grandis* had a 40% reduction in population size when ammonia was present at 5 ppm for 7 days, an LC_{50} is present at approximately 23 ppm in acute exposures (Havlik & Marking, 1987). Although levels of 23 ppm are unlikely in the Upper Cuyahoga River, levels of approximately 5 ppm can occur, as ammonia levels are chronically elevated downstream from the East Branch Reservoir due to periodic water releases (EPA, 2000).

Ammonia levels of approximately 5 mg/ml, created by the decomposition of animals after even moderate extirpation events, far exceed the LC_{50} of generalist unionid species such as *P. grandis*, one of the most common unionid mussels throughout the watersheds of the United States. These same ammonia levels are far more problematic for glochidia, with mortality rates reaching almost 100% after only a few days of exposure (Scheller, 1997).

Dissolved oxygen levels, according to the EPA, must have a minimal concentration level of 4-5 ppm to maintain macroinvertebrate communities. When measuring oxygen concentrations in the Upper Cuyahoga River, the EPA recorded average levels of approximately 8.5 ppm within the mainstem of the river. However, closer to the impoundments, dissolved oxygen levels plummeted, with average levels of 4.8 ppm within the East Branch and 5.8 ppm in the Western Branch (EPA, 2000). These levels are associated with average levels and often dissolved oxygen levels fall below life sustaining levels.

Figure 8

Zebra Mussels Parasite L. Nasuta

Note. Photo by Nikko Hogya

Interspecific Competition

Other stressors of unionid health are evident throughout the entirety of the Cuyahoga River. Parasitic species, such as *Dreissena polymorpha* were discovered infesting the Unionidae immediately downstream of Lake Rockwell in the middle portion of the river. Until documented within the 2015 survey, no previous evidence indicated *D. polymorpha* had successfully invaded this area. In addition to *D. polymorpha,* vast numbers of *Corbicula fluminea* valves were found scattered throughout the middle and lower portions of the Cuyahoga River. Although no live *C. fluminea* were recorded, this abundant valve cache indicates an abundant population that would have competed directly with the Unionidae, as well as increased competition pressure in lotic zones. Benthic sampling was not within the scope of this project, and further studies must be conducted to explore deeper into the sediment to confirm the existence of an extant population of *C. fluminea*.

Predation

An introduction event occurred in 1986, when 123 river otters were introduced from Louisiana and Arkansas into the watersheds of Northeast Ohio, including the Cuyahoga River (CVNP, 2017). Since then, otter populations have exploded, with river otters numbering in the hundreds. Popular within the CVNP, especially near Beaver Creek, river otters are spotted periodically during the surveys of the Lower Cuyahoga River. River otters were also spotted by our surveyors within the Middle Cuyahoga; however, sightings were not as common and occurred mostly in the western portion of the river.

In both 2012 and 2016, fishermen were questioned during surveys of the Upper Cuyahoga regarding the presence of river otters. According to the fishermen, encounters were common especially near Hiram, OH. When asked, many fishermen were irate with the otters' decimation of fish species and considered them a pest species. Although unionid numbers are too low to be a primary food source for otter populations, it is likely that the influx of this megafauna could disrupt unionid and host fish interactions, creating more pressure on unionid mussel populations (Owen et al., 2011).

Implications of Unionid Disappearance in the Cuyahoga River

In the past, literature emphasized trying to save unionid populations through water remediation and habitat restoration; however, efforts have seemed to accomplish little to mitigate decline within the Cuyahoga River. As population numbers are low, it is unlikely that the Unionidae adequately perform the ecosystem services associated with this taxon.

Results from surveys also suggest that there are too few unionids to adequately filter toxins or pollutants from the water column or sediment. Larger individual unionids are capable of filtering approximately 12 liters of water per day (Vaughn et al., 2004). However, these estimates are based on laboratory experiments, and studies suggest laboratory conditions are far more ideal than actual river conditions for mussel productivity (Vaughn, 2017). Evidence suggests that filtration rates are positively correlated with mussel size—and more specifically gill size—instead of species type or abundance, which was previously suspected but unsupported (Vaughn, 2017).

Filtration rates by unionid assemblages in natural systems can be estimated at far less than 12 L per day (Vaughn, 2017), and mussel abundance is low. These compounding factors indicate that unionid populations within the Cuyahoga River have done little to improve water quality. It is more likely that anthropogenic river remediation efforts, not unionid water filtration, are the causal agent for greatly improved water quality in the river.

Moreover, regarding filtration rates, diversity loss may be of little consequence. Recently, officials have suggested restoring unionid diversity and abundance within the Cuyahoga River. However, as filtration rates are correlated with mussel size, data suggest there is no need to increase diversity to fulfill the unionids' role as an ecosystem engineer (OEPA, 2012).

In addition to losing the role of ecosystem engineer within the Cuyahoga, unionid mussels are too small a population to be an advantageous prey source for any megafaunal groups, such as otters or muskrats, within the watershed (Owen et al., 2011). Moreover, there is at least anecdotal evidence to support that, in at least this watershed, mammalian predators have replaced bivalves with fish in their diet. It is hypothesized that this switch was made because fish species in the Cuyahoga are more abundant than unionids and slow swimming, making them easy prey sources (McDonald, 1989).

Implications for Future Reintroduction Efforts

Reintroduction or augmentation is the terminal goal of most remediation projects, especially in the recent past. In order to reintroduce native species, relevant personnel must first create suitable habitat to ensure the survivability of the reintroduced species. However, to correct the multitude of stressors to acceptable standards for unionid survival would require a great deal of collaborative effort amongst multiple federal, state, and local agencies. Moreover, the provision of suitable habitat for unionid reproductive success would be tremendously complex, requiring the monitoring of host fish populations and changes in water quality standards and water flow dynamics. To accomplish reintroduction would require the interdisciplinary collaboration and the compliance of numerous governmental agencies, including the EPA, OEPA, and metro parks from Geauga, Summit, Portage, and Cuyahoga counties, as well as the Cuyahoga Valley National Park. Results from surveys indicate that, although water quality and flow heterogeneity have improved, unionid populations remain imperiled throughout the Cuyahoga River. While historic water conditions have been greatly restored, all three areas of the Cuyahoga River exhibit either a significant decline or lack of recovery in species diversity and abundance.

The Cuyahoga River has historically been habitat for a variety of rare or state-endangered mussels. Though small in number, these species, such as *L. nasuta,* were represented as recently as 2012, and numbers of live individuals were expected to remain low. The significant loss of individuals of generalist unionid mussel species was unexpected, especially in the Upper and Middle Cuyahoga watersheds, as water quality in these area is suitable for human consumption and recreation. With numerous environmental impact studies completed by the EPA and the NEORSD, all levels of heavy metals, dissolved oxygen, and ammonia are well within federal and state standards. However, the species of interest for this project—*P. grandis, L. complanata*, and *L. siliquoidea*—continue to decline.

Estimates of mussel abundance indicate that current unionid populations are incapable of contributing much to ecosystem services, and the services that unionids typically provide to watersheds has been replaced by human remediation efforts. As human agency has restored many of the waterways within the United States to acceptable levels, it becomes indicative that, currently, their disappearance is far less impactful to the Cuyahoga River watershed than previously estimated. Moreover, with little indication that the Unionidae fulfill their role of the ecosystem engineers as observed in other, larger watersheds such as the Mississippi and Ohio rivers, reintroduction efforts should be explored within the Cuyahoga River. With no evidence to suggest that reintroduction efforts would be effective, as the causal agent of Unionid decline remains unknown, consideration should be given to whether reintroduction of unionids is appropriate until a collaborative framework is viable.

REFERENCES

Adler, J. (2002). Fables of the Cuyahoga: Reconstructing a history of environmental protection. *Fordham Environmental Law Review*, *331*, 330–331. https://doi.org/10.2139/ssrn.333140

Augspurger, T., Keller, A. E., Black, M. C., Cope, W. G., & Dwyer, F. J. (2003). Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. *Environmental Toxicology and Chemistry*, *22*(11), 2569–2575. https://doi.org/10.1897/02-339

Bednarek, A. T., & Hart, D. D. (2005). Modifying dam operations to restore rivers: Ecological responses to Tennessee River dam mitigation. *Ecological Applications*, *15*(3), 997–1008. https://doi.org/10.1890/04-0586

Begley, M. T. & Krebs, R. A. (2017). Application of EPA-produced biotic indices and physical stream measurements to assess freshwater mussel (Unionidae) habitat in the upper Mahoning River, Ohio. *Northeastern Naturalist*, 24, 1-14.

Benda, L., Andras, K., Miller, D., & Bigelow, P. (2004). Confluence effects in rivers: Interactions of basin scale, network geometry, and disturbance regimes. *Water Resources Research*, *40*(5), 1-15. https://doi.org/10.1029/2003WR002583

Benke, A. C. (1990). A perspective on America's vanishing streams. *Journal of the North American Benthological Society*, *9*(1), 77-88. http://www.jstor.org/stable/1467936

Besada, V., Manuel Andrade, J., Schultze, F., & José González, J. (2011). Monitoring of heavy metals in wild mussels (*Mytilus galloprovincialis*) from the Spanish North-

Atlantic coast. *Continental Shelf Research*, *31*(5), 457-465. https://doi.org/10.1016/j.csr.2010.04.011

Bobat, A. (2015). Thermal pollution caused by hydropower plants. In A. N. Bilge, A. Ö. Toy, & M. E. Günay (Eds.), *Energy systems and management* (pp. 19-32). Springer.

Bogan, A. E. (1993). Freshwater bivalve extinctions: Search for a cause. *American Zoologist*, *33*, 599-609.

City of Akron. (2016). *Lake Rockwell and Lake Pippen*. https://www.akronohio.gov/cms/Water/Watershed_Rockwell/index.html

Clay, P. A., Muehlbauer, J. D., & Doyle, M. W. (2015). Effect of tributary and braided confluences on aquatic macroinvertebrate communities and geomorphology in an alpine river watershed. *Freshwater Science*, *34*(3), 845–856. https://doi.org/10.1086/682329

Cohen, A. N., & Weinstein, A. (2001). *Zebra mussel's calcium threshold and implications for its potential distribution in North America*. San Francisco Estuary Institute. https://www.sfei.org/sites/default/files/biblio_files/2001-Zebramusselcalcium356.pdf

Cope, W. G., Hove, M. C., Waller, D. L., Hornbach, D. J., Bartsch, M. R., Cunningham, L. A., & Kapuscinski, A. R. (2003). Evaluation of relocation of unionid mussels to in situ refugia. *Journal of Molluscan Studies*, *69*(1), 27–34. https://doi.org/10.1093/mollus/69.1.27

Diamond, J. M., Bressler, D. W., & Serveiss, V. B. (2002). Assessing relationships between human land uses and the decline of native mussels, fish, and macroinvertebrates in the Clinch and Powell River watershed, USA. *Environmental Toxicology and Chemistry*, *21*(6), 1147-1155. https://doi.org/10.1002/etc.5620210606

Doyle, M. W., Stanley, E. H., Harbor, J. M., & Grant, G. S. (2003). Dam removal in the United States: Emerging needs for science and policy. *Eos*, *84*(4), 29. https://doi.org/10.1029/2003EO040001

Dubelko, J. (2015). *The 1916 Waterworks Tunnel disaster*. Cleveland Historical Society. https://clevelandhistorical.org/items/show/736

Duncan, D., Harvey, F., & Walker, M. (2007). *EPA guidelines: Regulatory monitoring and testing, water and wastewater sampling*. Environmental Protection Agency, South Australia. https://www.epa.sa.gov.au/files/8494_guide_wws.pdf

Dzierżyńska-Białończyk, A., Jermacz, Ł., Maćkiewicz, T., Gajewska, J., & Kobak, J. (2018). Mechanisms and impact of differential fouling of the zebra mussel Dreissena polymorpha on different unionid bivalves. *Freshwater Biology*, *63*(7), 687-699.

French, J. R. P., & Schloesser, D. W. (1996). Distribution and winter survival health of asian clams, corbicula fluminea, in the st. clair river, michigan. *Journal of Freshwater Ecology*, *11*(2), 183-192. https://doi.org/10.1080/02705060.1996.9663477

Foley, M. M., Magilligan, F. J., Torgersen, C. E., Major, J. J., Anderson, C. W., Connolly, P. J., Wieferich, D., Shafroth, P. B., Evans, J. E., Infante, D., & Craig, L. S. (2017). Landscape context and the biophysical response of rivers to dam removal in the United States. *PloS One*, *12*(7), 1-24. https://doi.org/10.1371/journal.pone.0180107

Gangloff, M. M., Hartfield, E. E., Werneke, D. C., & Feminella, J. W. (2011). Associations between small dams and mollusk assemblages in Alabama streams. *Journal of the North American Benthological Society*, *30*(4), 1107-1116. https://doi.org/10.1899/10-092.1

Gillis, P. L., & Mackie, G. L. (1994). Impact of the zebra mussel, Dreissena polymorpha, on populations of unionidae (Bivalvia) in Lake St. Clair. *Canadian Journal of Zoology*, *72*(7), 1260-1271. https://doi.org/10.1139/z94-168

Graf, D. L., & Cummings, K. S. (2007). Review of the systematics and global diversity of freshwater mussel species (Bivalvia: Unionoida). *Journal of Molluscan Studies*, *73*(4), 291–314. https://doi.org/10.1093/mollus/eym029

Havlik, M. E., & Marking, L. L. (1987). *Effects of contaminants on naiad mollusks (Unionidae): A review*. United States Fish and Wildlife Service. https://pubs.er.usgs.gov/publication/2001203

Hogya, N. P., Andrikanich, R. E., Trimbath, R., & Krebs, R.A. (2016). Consequences of dam removal on mussel assemblages (Unionidae) in the Cuyahoga River. *Ohio Journal of Science*, *117*, 6-15. https://doi.org/10.18061/ojs.v117i2.5307

Hornbach, D. J., Hove, M. C., Liu, H.-T., Schenck, F. R., Rubin, D., & Sansom, B. J. (2014). The influence of two differently sized dams on mussel assemblages and growth. *Hydrobiologia*, *724*(1), 279-291. https://doi.org/10.1007/s10750-013-1743-y

Howard, J. K., & Cuffey, K. M. (2006). The functional role of native freshwater mussels in the fluvial benthic environment. *Freshwater Biology*, *51*(3), 460–474. https://doi.org/10.1111/j.1365-2427.2005.01507.x

Huehner, M. K. (1985). *A survey of unionid mussel species of the Upper Cuyahoga River*. Hiram.

Hoggarth, M. A. (1990). *A study of the Unionidae of the upper Cuyahoga River*. Ohio Department of National Resources, Division of Natural Areas and Preserves.

Jelks, H. L., Walsh, S. J., Burkhead, N. M., Contreras-Balderas, S., Diaz-Pardo, E., Hendrickson, D. A., Lyons, J., Mandrak, N. E., McCormick, F., Nelson, J. S., Platania, S. P., Porter, B. A., Renaud, C. B., Schmitter-Soto, J. J., Taylor, E. B., & Warren, Jr., M. L. (2008). Endangered species: Conservation status of imperiled North American freshwater and diadromous fishes. *Fisheries*, *33*(8), 372-407.

Karatayev, A. Y., Burlakova, L. E., & Padilla, D. K. (2014). Zebra versus quagga mussels: A review of their spread, population dynamics, and ecosystem impacts. *Hydrobiologia*, *746*(1), 97-112. https://doi.org/10.1007/s10750-014-1901-x

Lauritsen, D. D. (1986). Filter-feeding in Corbicula fluminea and its effect on seston removal. *Journal of the North American Benthological Society*, *5*(3), 165-172. https://doi.org/10.2307/1467704

Lefevre, G., & Curtis, W. C. (1910). Reproduction and parasitism in the Unionid? *Journal of Experimental Zoology*, *9*(1), 79-116. https://doi.org/10.1002/jez.1400090105

Mackie, G. L. (1991). Biology of the exotic zebra mussel, Dreissena polymorpha, in relation to native bivalves and its potential impact in Lake St. Clair. *Hydrobiologia*, *219*(1), 251-268. https://doi.org/10.1007/BF00024759

Mackie, G. L., & Schloesser, D. W. (1996). Comparative biology of zebra mussels in Europe and North America: An overview. *American Zoologist*, *36*(3), 244-258. https://doi.org/10.1093/icb/36.3.244

Maheu, A., St-Hilaire, A., Caissie, D., & El-Jabi, N. (2016). Understanding the thermal regime of rivers influenced by small and medium size dams in Eastern Canada. *River Research and Applications*, *32*(10), 2032–2044. https://doi.org/10.1002/rra.3046

Major, J. J., East, A. E., O'Connor, J. E., Grant, G. E., Wilcox, A. C., Magirl, C. S., & Tullos, D. D. (2017). Geomorphic responses to dam removal in the United States–A two-decade perspective. In D. Tsutsumi, & J. B. Laronne (Eds.), *Gravel-bed rivers: Processes and disasters* (pp. 355-381). Wiley.

Mann, K. C., Peck, J. A., & Peck, M. Assessing dam pool sediment for understanding past, present, and future watershed dynamics: An example from the Cuyahoga River, Ohio. *Anthropocene*, *2*, 76-88. https://doi.org/10.1016/j.ancene.2013.08.001

McDonald, K. P. (1989). *Survival, home range, movements, habitat use, and feeding habits of reintroduced river otters in Ohio* [Unpublished doctoral dissertation]. The Ohio State University.

McMahon, R. F. (1996). The physiological ecology of the zebra mussel, Dreissena polymorpha, in North America and Europe. *American Zoologist*, *36*(3), 339-363. https://doi.org/10.1093/icb/36.3.339

McMahon, R. F. (2015). Implementation of a cost-effective monitoring and early detection program for zebra mussel invasion of Texas water bodies. In W. H. Wong & S. L. Gerstenberger (Eds.), *Biology and management of invasive quagga and zebra mussels in the western United States* (pp. 349-374). CRC Press.

Morris, T. J., & Corkum, L. D. (1996). Assemblage structure of freshwater mussels (Bivalvia:Unionidae) in rivers with grassy and forested riparian zones. *Journal of* *the North American Benthological Society*, *15*(4), 576-586. https://doi.org/10.2307/1467808

Mosley, M. P. (1985). River channel inventory, habitat and instream flow assessment. *Progress in Physical Geography*, *9*(4), 494-523. https://doi.org/10.1177/030913338500900402

Naimo, T. J. (1995). A review of the effects of heavy metals on freshwater mussels. *Ecotoxicology*, *4*(6), 341-362. https://doi.org/10.1007/BF00118870

National Park Service. (2017). *Cuyahoga Valley National Park mammals list*. https://www.nps.gov/cuva/learn/nature/animals.htm

Newton, T. J. (2003). The effects of ammonia on freshwater unionid mussels. *Environmental Toxicology and Chemistry, 22*(11), 1. https://doi.org/10.1897/03-84

Nickel, T. D., Welch, W. G., Cope, C. H., Hacker, R. A., Reed, A. K., Distler, D. A., Rogers, C. M., & Schneegurt, M. A. (2019). Reassessment of freshwater Unionid mussel diversity and abundance in the Walnut River Basin, Kansas. *Transactions of the Kansas Academy of Science*, *122*(1-2), 39-48.

Nicklin, L., & Balas, M. T. (2007). Correlation between Unionid mussel density and EPA habitat-assessment parameters. *Northeastern Naturalist*, *14*(2), 225-234. https://doi.org/10.1656/1092-6194(2007)14[225:CBUMDA]2.0.CO;2

Nobles, T., & Zhang, Y. (2011). Biodiversity loss in freshwater mussels: Importance, threats, and solutions. In O. Grillo & G. Venora (Eds.), *Biodiversity loss in a changing planet* (pp. 137-162). InTech.

Ohio EPA. (1999). *Biological and water quality study of the Cuyahoga River and selected tributaries, Volume 1: Geauga, Portage, Summit and Cuyahoga Counties*. https://www.epa.state.oh.us/portals/35/documents/cuyvol1.pdf

Olive, K. R. (1975). Benthic macroinvertebrates as indexes of water quality in the Scioto River basin, Ohio. *Ohio Journal of Science*, *73*(3), 129-149.

Owen, C. T., Mcgregor, M. A., Cobbs, G. A., & Alexander, J. E. (2011). Muskrat predation on a diverse unionid mussel community: Impacts of prey species composition, size and shape. *Freshwater Biology*, *56*(3), 554–564. https://doi.org/10.1111/j.1365-2427.2010.02523.x

Parry, H. E., & Pipe, R. K. (2004). Interactive effects of temperature and copper on immunocompetence and disease susceptibility in mussels (*Mytilus edulis*). *Aquatic Toxicology*, *69*(4), 311-325. https://doi.org/10.1016/j.aquatox.2004.06.003

Peyer, S. M., McCarthy, A. J., & Lee, C. E. (2009). Zebra mussels anchor byssal threads faster and tighter than quagga mussels in flow. *Journal of Experimental Biology*, *212*(13), 2027-2036. https://doi.org/10.1242/jeb.028688

Pigneur, L. M., Falisse, E., Roland, K., Everbecq, E., Deliège, J. F., Smitz, J. S., & Descy, J. P. (2014). Impact of invasive Asian clams, *C orbicula* spp., on a large river ecosystem. *Freshwater Biology*, *59*(3), 573–583. https://doi.org/10.1111/fwb.12286

Prochazka, J. M. A. S. T., Cope, W. G., & Lazaro, D. S. P. R. (2017). Polycyclic aromatic hydrocarbons in surface waters, sediments, and unionid mussels: Relation to road crossings and implications for chronic mussel exposure. *Hydrobiologica*, *810*, 465-476.

Quinn, A., Gallardo, B., & Aldridge, D. C. (2014). Quantifying the ecological niche overlap between two interacting invasive species: The zebra mussel (*Dreissena polymorpha*) and the quagga mussel (*Dreissena rostriformis bugensis*). *Aquatic Conservation: Marine and Freshwater Ecosystems*, *24*(3), 324-337. https://doi.org/10.1002/aqc.2414

Ricciardi, A., Neves, R. J., & Rasmussen, J. B. (1998). Impending extinctions of North American freshwater mussels (Unionoida) following the zebra mussel (*Dreissena polymorpha*) invasion. *Journal of Animal Ecology*, *67*(4), 613-619. https://doi.org/10.1046/j.1365-2656.1998.00220.x

Richter, B. D., Braun, D. P., Mendelson, M. A., & Master, L. L. (1997). Threats to imperiled freshwater fauna. *Conservation Biology*, *11*(5), 1081-1093. https://doi.org/10.1046/j.1523-1739.1997.96236.x

Ries, P., De Jager, N. R., Zigler, S. J., & Newton, T. J. (2016). Spatial patterns of native freshwater mussels in the Upper Mississippi River. *Freshwater Science*, *35*(3), 934-947.

Rodeles, A. A., Galicia, D., & Miranda, R. (2017). Recommendations for monitoring freshwater fishes in river restoration plans: A wasted opportunity for assessing impact. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *27*(4), 880-885. https://doi.org/10.1002/aqc.2753

Scheller, J. L. (1997). *The effect of die-offs of Asian clams (Corbicula Fluminea) on native freshwater mussels (Unionidae)* [Unpublished master's thesis]. Virginia Polytechnic Institute and State University.

Schloesser, D. W., Smithee, R. D., Longton, G. D., & Kovalak, W. P. (1997). Zebra mussel induced mortality of unionids in firm substrata of western Lake Erie and a habitat for survival. *American Malacological Bulletin*, *14*(1), 67-74.

Schwalb, A. N., Morris, T. J., Mandrak, N. E., & Cottenie, K. (2013). Distribution of unionid freshwater mussels depends on the distribution of host fishes on a regional scale. *Diversity and Distributions*, *19*(4), 446-454. https://doi.org/10.1111/j.1472-4642.2012.00940.x

Service, N. P., Heights, B., & Counties, S. (2008). *Occurrence of organic wastewater compounds in the Tinkers Creek Watershed and two other tributaries to the Cuyahoga River, Northeast Ohio*. United States Geological Survey. https://pubs.usgs.gov/sir/2008/5173/

Sethi, S. A., Selle, A. R., Doyle, M. W., Stanley, E. H., & Kitchel, H. E. (2004). Response of unionid mussels to dam removal in Koshkonong Creek, Wisconsin (USA). *Hydrobiologia*, *525*(1), 157-165. https://doi.org/10.1023/B:HYDR.0000038862.63229.56

Sietman, B. E., Whitney, S. D., Kelner, D. E., Blodgett, K. D., & Dunn, H. L. (2001). Post-extirpation recovery of the freshwater mussel (Bivalvia: Unionidae) fauna in the Upper Illinois River. *Journal of Freshwater Ecology*, *16*(2), 273-281. https://doi.org/10.1080/02705060.2001.9663813

Singer, E. E., & Gangloff, M. M. (2011). Effects of a small dam on freshwater mussel growth in an Alabama (USA) stream. *Freshwater Biology*, *56*(9), 1904-1915. https://doi.org/10.1111/j.1365-2427.2011.02608.x

Smith, D. C. (2001). *Pennak's freshwater invertebrates of the United States: Porifera to crustacea* (4th ed.). John Wiley & Sons.

Smith, D. C., Gates, M. A., Krebs, R. A., & Tevesz, M. J. S. (2002). *A survey of freshwater mussels (Unionidae) and other molluscs in the Cuyahoga Valley National Park.* Department of Biology, Geology, and Environmental Sciences, Cleveland State University.

Sparks, B. L., & Strayer, D. L. (1998). Effects of low dissolved oxygen on juvenile *Elliptio complanata* (Bivalvia: Unionidae). *Journal of the North American Benthological Society*, *17*(1), 129-134. https://doi.org/10.2307/1468057

Stein, B. A., & Flack, S. R. (1997). *Species report card: The state of U.S. plants and animals.* The Nature Conservancy.

Stradling, D., & Stradling, R. (2008). Perceptions of the burning river: Deindustrialization and Cleveland’s Cuyahoga River. *Environmental History*, *13*(3), 515-535. https://doi.org/10.1093/envhis/13.3.515

Strayer, D. L., & Malcom, H. M. (2018). Long-term responses of native bivalves (Unionidae and Sphaeriidae) to a Dreissena invasion. *Freshwater Science*, *37*(4), 697-711.

Teaford, J. C. (2017). The voices of the Rust Belt. *Middle West Review*, *4*(1), 171-176.

Tevesz, M. J. S., Rundo, L., Krebs, R. A., Redmond, B. G., & Dufresne, A. S. (2002). Changes in the freshwater mussel (Mollusca, Bivalvia) fauna of the Cuyahoga River, Ohio, since late prehistory. *Kirtlandia*, *53*, 13-18.

Tiemann, J. S., Douglass, S. A., Stodola, A. P., & Cummings, K. S. (2016). Effects of lowhead dams on freshwater mussels in the Vermilion River basin, Illinois, with comments on a natural dam removal. *Transactions of the Illinois State Academy of Science*, *109*, 1-7.

Tuckerman, S. (2006). *Environmental restoration of the Cuyahoga River through dam removal*. Geological Society of America Abstracts. https://gsa.confex.com/gsa/2006NC/finalprogram/abstract_102924.htm

Turgeon, D. D., Bogan, A. E., Coan, E. V., Emerson, W. K., Lyons, W. G., Pratt, W. L., Roper, C. F. E., Scheltema, A., Thompson, F. G., & Williams, J. D. (1988). Common and scientific names of aquatic vertebrates from the United States and Canada: Mollusks. Committee on Scientific and Vernacular Names of Mollusks of the Council of Systematic Malacologists, American Macalogical Union, Bethesda, MD.

United States Census Bureau. (2019). *Quick facts, Akron, Ohio* https://www.census.gov/quickfacts/akroncityohio

United States Environmental Protection Agency. (2000). *Total maximum daily loads for the Upper Cuyahoga River*. https://www.epa.gov/cuyahoga-river-aoc/restoring-cuyahoga-river-aoc-timeline

United States Environmental Protection Agency. (2017). *Restoring Cuyahoga River AOC (timeline)*. https://www.epa.gov/cuyahoga-river-aoc/restoring-cuyahoga-river-aoc-timeline

United States Geological Survey. (2005). *Estimated use of water in the United States: County-level data for 200*5. http://water.usgs.gov/watuse/data/2005/

United States Geological Survey. (2014). *USGS water data for the nation*. https://waterdata.usgs.gov/nwis

Vaughn, C. C. (2017). Ecosystem services provided by freshwater mussels. *Hydrobiologia*, *810*, 15-27. https://doi.org/10.1007/s10750-017-3139-x

Vaughn, C. C., Gido, K. B., & Spooner, D. E. (2004). Ecosystem processes performed by unionid mussels in stream mesocosms: Species roles and effects of abundance. *Hydrobiologia*, *527*(1), 35-47. https://doi.org/10.1023/B:HYDR.0000043180.30420.00

Vaughn, C. C., & Taylor, C. M. (1999). Impoundments and the decline of freshwater mussels: A case study of an extinction gradient. *Conservation Biology*, *13*(4), 912-920. https://doi.org/10.1046/j.1523-1739.1999.97343.x

Viarengo, A., & Canesi, L. (1991). Mussels as biological indicators of pollution. *Aquaculture*, *94*(2–3), 225-243. https://doi.org/10.1016/0044-8486(91)90120-V

Villella, R. F., Smith, D. R., & Lemarié, D. P. (2004). Estimating survival and recruitment in a freshwater mussel population using mark-recapture techniques. *The American Midland Naturalist*, *151*(1), 114-133. https://doi.org/10.1674/0003-0031(2004)151[0114:ESARIA]2.0.CO;2

Wang, N., Ingersoll, C. G., Hardesty, D. K., Ivey, C. D., Kunz, J. L., May, T. W., & Barnhart, M. C. (2007). Acute toxicity of copper, ammonia, and chlorine to glochidia and juveniles of freshwater mussels (Unionidae). *Environmental Toxicology and Chemistry*, *26*(10), 2036-2047. https://doi.org/10.1897/06-523R.1

Watters, G. T. (1996). Small dams as barriers to freshwater mussels (Bivalvia: Unionoida) and their hosts. *Biological Conservation*, *75*(1), 79-85. https://doi.org/10.1016/0006-3207(95)00034-8

Watters, G. T. (1999). Freshwater mussels and water quality: A review of the effects of hydrologic and instream habitat alterations. *Proceedings of the First Freshwater Mollusk Conservation Society Symposium*, 261-274. http://www.biosci.ohiostate.edu/%7B~%7Dmolluscs/OSUM2/papers/watters.pdf

Watters, G. T., Hoggarth, M. A., & Stansbery, D. H. (2009). *The freshwater mussels of Ohio* (2nd ed.). University of Ohio Press.

White, J. Q. (2007). *Tributary/mainstem interactions, the river continuum concept and the Grande Ronde River* [Unpublished paper]. University of California, Davis.

Zeitler, J. (2001). Restoration of the Cuyahoga River in Ohio, 1968-present. *Student On-Line Journal*, *7*(4), 1-13.

APPENDIX A. SITE SELECTION INFORMATION FOR CUYAHOGA RIVER SURVEYS

Site Number	Site Name	Latitude	Longitude
1	Old State Road	41.516	-81.096
2	Burton/Windsor (Upstream)	41.486	-81.106
3	Burton/Windsor (Downstream)	41.486	-81.106
4	Kinsman Road	41.465	-81.127
5	Butternut Road	41.499	-81.164
6	Butternut Road	41.496	-81.164
7	Butternut Road	41.496	-81.165
8	Butternut Road	41.495	-81.165
9	Fisher Road/Aquilla Road	41.488	-81.174
10	Fisher Road/Aquilla Road	41.487	-81.174
11	Fisher Road/Aquilla Road	41.487	-81.175
12	Cuyahoga River (East Branch Reservoir)	41.506	-81.105
13	Cuyahoga River at Eldon Russel Park	41.428	-81.154
14	Cuyahoga River (Eldon Russel)	41.396	-81.158

2015 Site Number	2015 Site Name	Latitude	Longitude
1	The Valley	41.1413	-81.5622
2	Akron-Peninsula Rd	41.136	-81.5479
3	Akron-Peninsula Rd	41.136	-81.5479
4	Cuyahoga St	41.1169	-81.525
5	State Rd	41.1234	-81.5123
6	Falls Rd	41.1283	-81.4678
7	Oak Park (downstream)	41.1483	-81.4678
8	Oak Park (upstream)	41.1483	-81.4678
9	Water-works (downstream)	41.1447	-81.4593
10	Water-works (upstream)	41.1447	-81.4593
11	Bike and Hike Trail	41.1478	-81.4495
12	Brust Park (downstream)	41.1428	-81.4392
13	Brust Park (upstream)	41.1418	-81.4368
14	Riverside Park	41.1384	-81.412
15	Middlebury Bridge	41.1378	-81.391
16	Bike-Train Bridge	41.143	-81.373

Site Number	Common Name	Latitude	Longitude
1	Bath Road	41.16255	-81.574167
2	Neitenbach Farm	41.18407	-81.577441
3	Ira Road	41.181365	-81.583492
4	Bolanz Road	41.200833	-81.568611
5	Everett Covered Bridge	41.203889	-81.583056
6	Riverview Road	41.263373	-81.558549
7	Stine Road	41.254897	-81.549105
8	Hines Hill Road	41.263373	-81.558549
9	Vaughn Road	41.288854	-81.56515
10	82 Dam	41.321173	-81.587522
11	Fitzwater Road	41.356917	-81.597934
12	Tinkers Creek Road	41.364284	-81.610459
13	Canal Exploration Center	41.373205	-81.614967
14	Stone Road	41.382748	-81.623188
15	Rockside Station	41.393655	-81.629626

APPENDIX B: RESULTS OF UPPER CUYAHOGA RIVER SURVEY COMPLETED BY HOGGARTH (1990)

Species	Live	Valves
A.ferussacianus	11	2
L. siliquoidea	334	116
L. complanata	274	110
L. compressa	33	15
L. costata	63	26
L. nasuta	87	51
P. grandis	1171	530
S. undulatus	38	14
U. imbecillis	9	3

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
1	Lasmigona	complanata	41.428	-81.154	Geauga	Old State Road below reservoir	2012	0	1
2	Ligumia	nasuta	41.428	-81.154	Geauga	Old State Road below reservoir	2012	1	28
3	Pyganodon	grandis	41.428	-81.154	Geauga	Old State Road below reservoir	2012	9	14
4	Lasmigona	complanata	41.485845	-81.106933	Geauga	Burton/Windsor (Upstream)	2012	0	2
5	Pyganodon	grandis	41.485845	-81.106933	Geauga	Burton/Windsor (Upstream)	2012	2	7
6	Strophitus	undulatus	41.485845	-81.106933	Geauga	Burton/Windsor (Upstream)	2012	1	0
7	Toxolasma	parvum	41.485845	-81.106933	Geauga	Burton/Windsor (Upstream)	2012	1	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
8	Lasmigona	complanata	41.485081	-81.106924	Geauga	Burton/Windsor (Downstream)	2012	4	1
9	Ligumia	nasuta	41.485081	-81.106924	Geauga	Burton/Windsor (Downstream)	2012	2	0
10	Toxolasma	parvum	41.485081	-81.106924	Geauga	Burton/Windsor (Downstream)	2012	8	1
11	Lasmigona	complanata	41.465153	-81.126442	Geauga	Kinsman Road	2012	9	3
12	Ligumia	nasuta	41.465153	-81.126442	Geauga	Kinsman Road	2012	1	2
13	Pyganodon	grandis	41.465153	-81.126442	Geauga	Kinsman Road	2012	1	4
14	Strophitus	undulatus	41.465153	-81.126442	Geauga	Kinsman Road	2012	3	1
15	Utterbackia	imbecillis	41.465153	-81.126442	Geauga	Kinsman Road	2012	0	2
16	Lasmigona	complanata	41.499722	-81.164167	Geauga	Butternut Road1	2012	12	12

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
17	Pyganodon	grandis	41.499722	-81.164167	Geauga	Butternut Road1	2012	7	37
18	Lampsilis	siliquoidea	41.497129	-81.164981	Geauga	Butternut Road2	2012	0	3
19	Lasmigona	complanata	41.497129	-81.164981	Geauga	Butternut Road2	2012	17	11
20	Lasmigona	costata	41.497129	-81.164981	Geauga	Butternut Road2	2012	0	1
21	Pyganodon	grandis	41.497129	-81.164981	Geauga	Butternut Road2	2012	4	28
22	Lampsilis	siliquoidea	41.496207	-81.16561	Geauga	Butternut Road3	2012	0	1
23	Lasmigona	complanata	41.496207	-81.16561	Geauga	Butternut Road3	2012	2	0
24	Pyganodon	grandis	41.496207	-81.16561	Geauga	Butternut Road3	2012	5	43
25	Lampsilis	siliquoidea	41.494976	-81.166352	Geauga	Butternut Road4	2012	0	3
26	Lasmigona	costata	41.494976	-81.166352	Geauga	Butternut Road4	2012	0	1
27	Pyganodon	grandis	41.494976	-81.166352	Geauga	Butternut Road4	2012	1	13

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
28	Strophitus	undulatus	41.494976	-81.166352	Geauga	Butternut Road4	2012	0	2
29	Lampsilis	siliquoidea	41.488438	-81.174424	Geauga	Fisher Road/Aquilla Road1	2012	6	9
30	Lasmigona	complanata	41.488438	-81.174424	Geauga	Fisher Road/Aquilla Road1	2012	4	20
31	Pyganodon	grandis	41.488438	-81.174424	Geauga	Fisher Road/Aquilla Road1	2012	13	6
32	Lampsilis	siliquoidea	41.487516	-81.174808	Geauga	Fisher Road/Aquilla Road2	2012	3	10
33	Lasmigona	complanata	41.487516	-81.174808	Geauga	Fisher Road/Aquilla Road2	2012	14	7
34	Pyganodon	grandis	41.487516	-81.174808	Geauga	Fisher Road/Aquilla Road2	2012	11	3

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
35	Lampsilis	siliquoidea	41.486684	-81.175622	Geauga	Fisher Road/Aquilla Road3	2012	11	0
36	Lasmigona	complanata	41.486684	-81.175622	Geauga	Fisher Road/Aquilla Road3	2012	8	30
37	Pyganodon	grandis	41.486684	-81.175622	Geauga	Fisher Road/Aquilla Road3	2012	11	30
38	Utterbackia	imbecillis	41.486684	-81.175622	Geauga	Fisher Road/Aquilla Road3	2012	0	1
39	Ligumia	nasuta	41.516528	-81.095688	Geauga	East Branch Reservoir	2012	0	1
40	Pyganodon	grandis	41.516528	-81.095688	Geauga	East Branch Reservoir	2012	0	13
41	Utterbackia	imbecillis	41.516528	-81.095688	Geauga	East Branch Reservoir	2012	0	1

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
42	Lampsilis	siliquoidea	41.428	-81.154	Geauga	Eldon Russel Park1	2012	1	0
43	Lasmigona	complanata	41.428	-81.154	Geauga	Eldon Russel Park1	2012	2	0
44	Ligumia	nasuta	41.428	-81.154	Geauga	Eldon Russel Park1	2012	1	0
45	Pyganodon	grandis	41.428	-81.154	Geauga	Eldon Russel Park1	2012	0	1
46	Utterbackia	imbecillis	41.428	-81.154	Geauga	Eldon Russel Park1	2012	4	1
47	Lasmigona	complanata	41.396429	-81.156626	Geauga	below Eldon Russel Park	2012	5	0
48	Strophitus	undulatus	41.396429	-81.156626	Geauga	below Eldon Russel Park	2012	1	0
49	Lampsilis	siliquoidea	41.365652	-81.162045	Geauga	Eldon Russel Park below 422	2012	5	1
50	Lasmigona	complanata	41.365652	-81.162045	Geauga	Eldon Russel Park below 422	2012	6	3

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
51	Pyganodon	grandis	41.365652	-81.162045	Geauga	Eldon Russel Park below 422	2012	3	2
52	Lampsilis	siliquoidea	41.356	-81.163	Portage	Rapids Rd above Black Brook	2012	0	1
53	Lasmigona	complanata	41.356	-81.163	Portage	Rapids Rd above Black Brook	2012	3	0
54	Pyganodon	grandis	41.356	-81.163	Portage	Rapids Rd above Black Brook	2012	0	2
55	Lampsilis	siliquoidea	41.349379	-81.164386	Portage	Below Black Brook	2012	2	0
56	Lasmigona	complanata	41.349379	-81.164386	Portage	Below Black Brook	2012	6	4
57	Pyganodon	grandis	41.349379	-81.164386	Portage	Below Black Brook	2012	2	0
58	Lasmigona	complanata	41.341449	-81.165899	Portage	Winchell and Thrasher Rd	2012	4	2

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
59	Pyganodon	grandis	41.341449	-81.165899	Portage	Winchell and Thrasher Rd	2012	3	0
60	Lampsilis	siliquoidea	41.338056	-81.166944	Portage	Allyn Rd	2012	2	7
61	Lasmigona	complanata	41.338056	-81.166944	Portage	Allyn Rd	2012	6	4
62	Ligumia	nasuta	41.338056	-81.166944	Portage	Allyn Rd	2012	0	1
63	Pyganodon	grandis	41.338056	-81.166944	Portage	Allyn Rd	2012	2	0
64	Lampsilis	siliquoidea	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	2012	30	0
65	Lasmigona	complanata	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	2012	30	3
66	Lasmigona	costata	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	2012	30	1

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
67	Ligumia	nasuta	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	2012	6	2
68	Pyganodon	grandis	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	2012	27	2
69	Strophitus	undulatus	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	2012	12	1
70	Lampsilis	siliquoidea	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	2012	4	2
71	Lasmigona	complanata	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	2012	3	1
72	Lasmigona	costata	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	2012	0	2
73	Pyganodon	grandis	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	2012	0	5

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
74	Strophitus	undulatus	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	2012	3	2
75	Ligumia	nasuta	41.318913	-81.180399	Portage	Abbot Rd Camp Hi 3	2012	3	0
76	Lampsilis	siliquoidea	41.325869	-81.172837	Portage	at Camp Hi	2012	3	1
77	Lasmigona	complanata	41.325869	-81.172837	Portage	at Camp Hi	2012	5	1
78	Ligumia	nasuta	41.325869	-81.172837	Portage	at Camp Hi	2012	4	0
79	Pyganodon	grandis	41.325869	-81.172837	Portage	at Camp Hi	2012	0	6
80	Pyganodon	grandis	41.485845	-81.106933	Geauga	Burton/Windsor (Upstream)	2016	1	3
81	Pyganodon	grandis	41.465153	-81.126442	Geauga	Kinsman Road	2016	0	5
82	Lasmigona	complanata	41.499722	-81.164167	Geauga	Butternut Road1	2016	3	6

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
83	Pyganodon	grandis	41.499722	-81.164167	Geauga	Butternut Road1	2016	4	21
84	Lasmigona	complanata	41.497129	-81.164981	Geauga	Butternut Road2	2016	9	12
85	Pyganodon	grandis	41.497129	-81.164981	Geauga	Butternut Road2	2016	4	9
86	Pyganodon	grandis	41.496207	-81.16561	Geauga	Butternut Road3	2016	3	12
87	Lampsilis	siliquoidea	41.488438	-81.174424	Geauga	Fisher Road/Aquilla Road1	2016	2	3
88	Pyganodon	grandis	41.488438	-81.174424	Geauga	Fisher Road/Aquilla Road1	2016	7	3
89	Lasmigona	complanata	41.487516	-81.174808	Geauga	Fisher Road/Aquilla Road2	2016	6	2
90	Pyganodon	grandis	41.487516	-81.174808	Geauga	Fisher Road/Aquilla Road2	2016	9	6

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
91	Lampsilis	siliquoidea	41.486684	-81.175622	Geauga	Fisher Road/Aquilla Road3	2016	0	4
92	Pyganodon	grandis	41.486684	-81.175622	Geauga	Fisher Road/Aquilla Road3	2016	0	7
93	Lampsilis	siliquoidea	41.365652	-81.162045	Geauga	Eldon Russel Park below 422	2016	2	0
94	Lasmigona	complanata	41.365652	-81.162045	Geauga	Eldon Russel Park below 422	2016	2	1
95	Lampsilis	siliquoidea	41.341449	-81.165899	Portage	Winchell and Thrasher Rd	2016	1	0
96	Lampsilis	siliquoidea	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	2016	5	3
97	Lasmigona	complanata	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	2016	14	13

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
98	Ligumia	nasuta	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	2016	1	0
99	Pyganodon	grandis	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	2016	7	0
100	Strophitus	undulatus	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	2016	3	4
101	Lasmigona	complanata	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	2016	5	0
102	Anodontoides	ferussacianus	41.325869	-81.172837	Portage	at Camp Hi	2016	8	0
103	Lampsilis	siliquoidea	41.325869	-81.172837	Portage	at Camp Hi	2016	3	0
104	Lasmigona	costata	41.325869	-81.172837	Portage	at Camp Hi	2016	8	0
105	Ligumia	nasuta	41.325869	-81.172837	Portage	at Camp Hi	2016	4	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
106	Anodontoides	ferussacianus	41.485845	-81.106933	Geauga	Burton/Windsor (Upstream)	1990	8	2
107	Pyganodon	grandis	41.485845	-81.106933	Geauga	Burton/Windsor (Upstream)	1990	10	2
108	Strophitus	undulatus	41.485845	-81.106933	Geauga	Burton/Windsor (Upstream)	1990	0	1
109	Lampsilis	siliquoidea	41.485081	-81.106924	Geauga	Burton/Windsor (Downstream)	1990	0	2
110	Lasmigona	complanata	41.485081	-81.106924	Geauga	Burton/Windsor (Downstream)	1990	0	2
111	Lasmigona	costata	41.485081	-81.106924	Geauga	Burton/Windsor (Downstream)	1990	0	5
112	Ligumia	nasuta	41.485081	-81.106924	Geauga	Burton/Windsor (Downstream)	1990	6	12

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
113	Pyganodon	grandis	41.485081	-81.106924	Geauga	Burton/Windsor (Downstream)	1990	5	10
114	Utterbackia	imbecillis	41.485081	-81.106924	Geauga	Burton/Windsor (Downstream)	1990	2	0
115	Pyganodon	grandis	41.465153	-81.126442	Geauga	Kinsman Road	1990	1	0
116	Lampsilis	siliquoidea	41.499722	-81.164167	Geauga	Butternut Road1	1990	2	6
117	Lasmigona	complanata	41.499722	-81.164167	Geauga	Butternut Road1	1990	3	4
118	Lasmigona	costata	41.499722	-81.164167	Geauga	Butternut Road1	1990	0	1
119	Ligumia	nasuta	41.499722	-81.164167	Geauga	Butternut Road1	1990	0	3
120	Pyganodon	grandis	41.499722	-81.164167	Geauga	Butternut Road1	1990	13	16
121	Strophitus	undulatus	41.499722	-81.164167	Geauga	Butternut Road1	1990	0	1
122	Utterbackia	imbecillis	41.499722	-81.164167	Geauga	Butternut Road1	1990	0	3

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
123	Pyganodon	grandis	41.496207	-81.16561	Geauga	Butternut Road3	1990	0	1
124	Lampsilis	siliquoidea	41.488438	-81.174424	Geauga	Fisher Road/Aquilla Road1	1990	0	1
125	Pyganodon	grandis	41.488438	-81.174424	Geauga	Fisher Road/Aquilla Road1	1990	1	6
126	Lampsilis	siliquoidea	41.487516	-81.174808	Geauga	Fisher Road/Aquilla Road2	1990	3	2
127	Lasmigona	complanata	41.487516	-81.174808	Geauga	Fisher Road/Aquilla Road2	1990	1	0
128	Ligumia	nasuta	41.487516	-81.174808	Geauga	Fisher Road/Aquilla Road2	1990	0	1
129	Pyganodon	grandis	41.487516	-81.174808	Geauga	Fisher Road/Aquilla Road2	1990	58	22

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
130	Utterbackia	imbecillis	41.487516	-81.174808	Geauga	Fisher Road/Aquilla Road2	1990	0	1
131	Lampsilis	siliquoidea	41.428	-81.154	Geauga	Eldon Russel Park1	1990	1	2
132	Lasmigona	complanata	41.428	-81.154	Geauga	Eldon Russel Park1	1990	50	0
133	Ligumia	nasuta	41.428	-81.154	Geauga	Eldon Russel Park1	1990	3	0
134	Pyganodon	grandis	41.428	-81.154	Geauga	Eldon Russel Park1	1990	100	4
135	Pyganodon	grandis	41.365652	-81.162045	Geauga	Eldon Russel Park below 422	1990	3	1
136	Lampsilis	siliquoidea	41.356	-81.163	Portage	Rapids Rd above Black Brook	1990	1	0
137	Lasmigona	complanata	41.356	-81.163	Portage	Rapids Rd above Black Brook	1990	4	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
138	Ligumia	nasuta	41.356	-81.163	Portage	Rapids Rd above Black Brook	1990	3	0
139	Pyganodon	grandis	41.356	-81.163	Portage	Rapids Rd above Black Brook	1990	27	0
140	Strophitus	undulatus	41.356	-81.163	Portage	Rapids Rd above Black Brook	1990	3	0
141	Lasmigona	compressa	41.356	-81.163	Portage	Rapids Rd above Black Brook	1990	3	0
142	Lampsilis	siliquoidea	41.349379	-81.164386	Portage	Below Black Brook	1990	4	6
143	Lasmigona	complanata	41.349379	-81.164386	Portage	Below Black Brook	1990	16	4
144	Lasmigona	costata	41.349379	-81.164386	Portage	Below Black Brook	1990	0	1
145	Ligumia	nasuta	41.349379	-81.164386	Portage	Below Black Brook	1990	2	5
146	Pyganodon	grandis	41.349379	-81.164386	Portage	Below Black Brook	1990	31	11

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
147	Strophitus	undulatus	41.349379	-81.164386	Portage	Below Black Brook	1990	0	4
148	Lasmigona	compressa	41.349379	-81.164386	Portage	Below Black Brook	1990	1	2
149	Lampsilis	siliquoidea	41.341449	-81.165899	Portage	Winchell and Thrasher Rd	1990	6	0
150	Lasmigona	complanata	41.341449	-81.165899	Portage	Winchell and Thrasher Rd	1990	3	0
151	Lasmigona	costata	41.341449	-81.165899	Portage	Winchell and Thrasher Rd	1990	1	0
152	Ligumia	nasuta	41.341449	-81.165899	Portage	Winchell and Thrasher Rd	1990	3	0
153	Pyganodon	grandis	41.341449	-81.165899	Portage	Winchell and Thrasher Rd	1990	6	0
154	Lampsilis	siliquoidea	41.338056	-81.166944	Portage	Allyn Rd	1990	0	2

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
155	Pyganodon	grandis	41.338056	-81.166944	Portage	Allyn Rd	1990	0	1
156	Lampsilis	siliquoidea	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	1990	2	0
157	Lasmigona	complanata	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	1990	2	0
158	Ligumia	nasuta	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	1990	4	0
159	Pyganodon	grandis	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	1990	15	0
160	Strophitus	undulatus	41.327964	-81.171292	Portage	Abbot Rd Camp Hi 1	1990	7	0
161	Lampsilis	siliquoidea	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	1990	11	3

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
162	Lasmigona	complanata	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	1990	9	1
163	Lasmigona	costata	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	1990	3	0
164	Ligumia	nasuta	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	1990	3	0
165	Pyganodon	grandis	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	1990	7	2
166	Strophitus	undulatus	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	1990	12	1
167	Lasmigona	compressa	41.32087	-81.176603	Portage	Abbot Rd Camp Hi 2	1990	1	0
168	Lampsilis	siliquoidea	41.2449	-81.2859	Portage	St 303	2015	15	n/a

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
169	Lasmigona	costata	41.2449	-81.2859	Portage	St 303	2015	0	n/a
170	Ligumia	nasuta	41.2449	-81.2859	Portage	St 303	2015	3	n/a
171	Pyganodon	grandis	41.2449	-81.2859	Portage	St 303	2015	4	n/a
172	Lampsilis	siliquoidea	41.2689	-81.2463	Portage	St 164	2015	25	n/a
173	Lasmigona	costata	41.2689	-81.2463	Portage	St 164	2015	1	n/a
174	Ligumia	nasuta	41.2689	-81.2463	Portage	St 164	2015	1	n/a
175	Pyganodon	grandis	41.2689	-81.2463	Portage	St 164	2015	11	n/a
176	Lampsilis	siliquoidea	41.325869	-81.172837	Portage	at Camp Hi	2015	92	n/a
177	Lasmigona	costata	41.325869	-81.172837	Portage	at Camp Hi	2015	2	n/a
178	Ligumia	nasuta	41.325869	-81.172837	Portage	at Camp Hi	2015	10	n/a
179	Pyganodon	grandis	41.325869	-81.172837	Portage	at Camp Hi	2015	23	n/a

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
180	Lampsilis	siliquoidea	41.1384	-81.412	Summit	Riverside Park	2015	1	18
181	Ligumia	nasuta	41.1384	-81.412	Summit	Riverside Park	2015	1	3
182	Pyganodon	grandis	41.1384	-81.412	Summit	Riverside Park	2015	3	20
183	Lampsilis	siliquoidea	41.1418	-81.4368	Summit	Brust Park	2015	0	2
184	Ligumia	nasuta	41.1418	-81.4368	Summit	Brust Park	2015	0	8
185	Lampsilis	siliquoidea	41.1478	-81.4495	Summit	Bike & Hike Trail	2015	0	1
186	Ligumia	nasuta	41.1478	-81.4495	Summit	Bike & Hike Trail	2015	0	11
187	Pyganodon	grandis	41.1478	-81.4495	Summit	Bike & Hike Trail	2015	0	15
188	Strophitus	undulatus	41.1478	-81.4495	Summit	Bike & Hike Trail	2015	0	1
189	Lampsilis	siliquoidea	41.1447	-81.4593	Summit	water works	2015	0	14
190	Ligumia	nasuta	41.1447	-81.4593	Summit	water works	2015	0	5

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
191	Pyganodon	grandis	41.1447	-81.4593	Summit	water works	2015	0	30
192	Toxolasma	parvum	41.1447	-81.4593	Summit	water works	2015	0	2
193	Lampsilis	siliquoidea	41.1447	-81.4593	Summit	water works2	2015	0	10
194	Lasmigona	costata	41.1447	-81.4593	Summit	water works2	2015	0	3
195	Ligumia	nasuta	41.1447	-81.4593	Summit	water works2	2015	0	11
196	Pyganodon	grandis	41.1447	-81.4593	Summit	water works2	2015	0	30
197	Strophitus	undulatus	41.1447	-81.4593	Summit	water works2	2015	0	2
198	Lasmigona	compressa	41.1483	-81.4678	Summit	Oak Park	2015	0	3
199	Lasmigona	costata	41.1483	-81.4678	Summit	Oak Park	2015	0	1
200	Ligumia	nasuta	41.1483	-81.4678	Summit	Oak Park	2015	0	1
201	Pyganodon	grandis	41.1483	-81.4678	Summit	Oak Park	2015	0	20

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
202	Lampsilis	siliquoidea	41.1483	-81.4678	Summit	Oak Park2	2015	0	1
203	Lasmigona	compressa	41.1483	-81.4678	Summit	Oak Park2	2015	0	1
204	Ligumia	nasuta	41.1483	-81.4678	Summit	Oak Park2	2015	0	4
205	Pyganodon	grandis	41.1483	-81.4678	Summit	Oak Park2	2015	0	32
206	Strophitus	undulatus	41.1483	-81.4678	Summit	Oak Park2	2015	0	3
207	Pyganodon	grandis	41.1283	-81.4841	Summit	Falls Rd.	2015	0	1
208	Lasmigona	complanata	41.1283	-81.4841	Summit	Akron-Peninsula Rd.	2015	0	1
209	Lampsilis	siliquoidea	41.1378	-81.391	Summit	Middlebury Bridge	2015	2	44
210	Ligumia	nasuta	41.1378	-81.391	Summit	Middlebury Bridge	2015	0	30
211	Pyganodon	grandis	41.1378	-81.391	Summit	Middlebury Bridge	2015	2	11

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
212	Toxolasma	parvum	41.1378	-81.391	Summit	Middlebury Bridge	2015	0	3
213	Utterbackia	imbecillis	41.1378	-81.391	Summit	Middlebury Bridge	2015	0	3
214	Lampsilis	siliquoidea	41.143	-81.373	Summit	Bike-Train Bridge	2015	1	2
215	Ligumia	nasuta	41.143	-81.373	Summit	Bike-Train Bridge	2015	0	4
216	Pyganodon	grandis	41.143	-81.373	Summit	Bike-Train Bridge	2015	0	8
217	Lampsilis	siliquoidea	41.1498	-81.3671	Summit	Fuller Park	2015	3	7
218	Ligumia	nasuta	41.1498	-81.3671	Summit	Fuller Park	2015	1	6
219	Pyganodon	grandis	41.1498	-81.3671	Summit	Fuller Park	2015	1	0
220	Lampsilis	siliquoidea	41.1498	-81.3671	Summit	Fuller Park	2015	20	13
221	Lasmigona	compressa	41.1498	-81.3671	Summit	Fuller Park	2015	0	1
222	Ligumia	nasuta	41.1498	-81.3671	Summit	Fuller Park	2015	0	3

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
223	Pyganodon	grandis	41.1498	-81.3671	Summit	Fuller Park	2015	0	8
224	Lampsilis	siliquoidea	41.1685	-81.3466	Summit	Knolls Rd.	2015	1	0
225	Ligumia	nasuta	41.1685	-81.3466	Summit	Knolls Rd.	2015	0	6
226	Pyganodon	grandis	41.1685	-81.3466	Summit	Knolls Rd.	2015	0	28
227	Lampsilis	siliquoidea	41.1799	-81.336	Summit	Ravenna Rd.	2015	3	0
228	Ligumia	nasuta	41.1799	-81.336	Summit	Ravenna Rd.	2015	0	1
229	Pyganodon	grandis	41.539803	-81.169879	Geauga	West 1	1998	1	0
230	Utterbackia	imbecillis	41.539803	-81.169879	Geauga	West 1	1998	1	0
231	Ligumia	nasuta	41.530729	-81.170406	Geauga	West 2	1998	1	0
232	Pyganodon	grandis	41.530729	-81.170406	Geauga	West 2	1998	32	3
233	Utterbackia	imbecillis	41.530729	-81.170406	Geauga	West 2	1998	1	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
234	Lampsilis	siliquoidea	41.526748	-81.170513	Geauga	West 3	1998	0	1
235	Lasmigona	costata	41.526748	-81.170513	Geauga	West 3	1998	0	1
236	Ligumia	nasuta	41.526748	-81.170513	Geauga	West 3	1998	1	1
237	Pyganodon	grandis	41.526748	-81.170513	Geauga	West 3	1998	50	3
238	Anodontoides	ferussacianus	41.51846	-81.17257	Geauga	West 4	1998	1	0
239	Lampsilis	siliquoidea	41.51846	-81.17257	Geauga	West 4	1998	1	0
240	Ligumia	nasuta	41.51846	-81.17257	Geauga	West 4	1998	3	0
241	Pyganodon	grandis	41.51846	-81.17257	Geauga	West 4	1998	13	3
242	Anodontoides	ferussacianus	41.513272	-81.172955	Geauga	West 5	1998	2	0
243	Lasmigona	complanata	41.513272	-81.172955	Geauga	West 5	1998	1	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
244	Ligumia	nasuta	41.513272	-81.172955	Geauga	West 5	1998	22	0
245	Pyganodon	grandis	41.513272	-81.172955	Geauga	West 5	1998	43	0
246	Pyganodon	grandis	41.505211	-81.168222	Geauga	West 6	1998	1	1
247	Lampsilis	siliquoidea	41.496021	-81.165698	Geauga	West 7	1998	2	0
248	Lasmigona	complanata	41.496021	-81.165698	Geauga	West 7	1998	0	2
249	Lasmigona	costata	41.496021	-81.165698	Geauga	West 7	1998	0	1
250	Ligumia	nasuta	41.496021	-81.165698	Geauga	West 7	1998	0	1
251	Pyganodon	grandis	41.496021	-81.165698	Geauga	West 7	1998	7	3
252	Lampsilis	siliquoidea	41.493694	-81.167511	Geauga	West 8	1998	32	5
253	Lasmigona	complanata	41.493694	-81.167511	Geauga	West 8	1998	18	0
254	Lasmigona	compressa	41.493694	-81.167511	Geauga	West 8	1998	1	1

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
255	Lasmigona	costata	41.493694	-81.167511	Geauga	West 8	1998	1	0
256	Ligumia	nasuta	41.493694	-81.167511	Geauga	West 8	1998	1	0
257	Pyganodon	grandis	41.493694	-81.167511	Geauga	West 8	1998	56	29
258	Lampsilis	siliquoidea	41.489638	-81.171634	Geauga	West 9	1998	21	1
259	Lasmigona	complanata	41.489638	-81.171634	Geauga	West 9	1998	29	3
260	Ligumia	nasuta	41.489638	-81.171634	Geauga	West 9	1998	1	0
261	Pyganodon	grandis	41.489638	-81.171634	Geauga	West 9	1998	14	16
262	Lampsilis	siliquoidea	41.486384	-81.175742	Geauga	West 10	1998	18	0
263	Lasmigona	complanata	41.486384	-81.175742	Geauga	West 10	1998	8	1
264	Lasmigona	compressa	41.486384	-81.175742	Geauga	West 10	1998	0	1
265	Lasmigona	costata	41.486384	-81.175742	Geauga	West 10	1998	2	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
266	Pyganodon	grandis	41.486384	-81.175742	Geauga	West 10	1998	48	20
267	Lampsilis	siliquoidea	41.476991	-81.181587	Geauga	West 11	1998	15	1
268	Lasmigona	complanata	41.476991	-81.181587	Geauga	West 11	1998	17	0
269	Lasmigona	costata	41.476991	-81.181587	Geauga	West 11	1998	2	0
270	Ligumia	nasuta	41.476991	-81.181587	Geauga	West 11	1998	0	1
271	Pyganodon	grandis	41.476991	-81.181587	Geauga	West 11	1998	14	40
272	Lampsilis	siliquoidea	41.468481	-81.178121	Geauga	West 12	1998	4	0
273	Lasmigona	complanata	41.468481	-81.178121	Geauga	West 12	1998	11	17
274	Lasmigona	compressa	41.468481	-81.178121	Geauga	West 12	1998	0	1
275	Lasmigona	costata	41.468481	-81.178121	Geauga	West 12	1998	6	2
276	Ligumia	nasuta	41.468481	-81.178121	Geauga	West 12	1998	1	1

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
277	Pyganodon	grandis	41.468481	-81.178121	Geauga	West 12	1998	37	72
278	Lampsilis	siliquoidea	41.465929	-81.17792	Geauga	West 13	1998	21	7
279	Lasmigona	complanata	41.465929	-81.17792	Geauga	West 13	1998	9	1
280	Lasmigona	compressa	41.465929	-81.17792	Geauga	West 13	1998	1	1
281	Lasmigona	costata	41.465929	-81.17792	Geauga	West 13	1998	3	2
282	Pyganodon	grandis	41.465929	-81.17792	Geauga	West 13	1998	28	51
283	Lampsilis	siliquoidea	41.461637	-81.172198	Geauga	West 14	1998	1	6
284	Lasmigona	complanata	41.461637	-81.172198	Geauga	West 14	1998	6	4
285	Lasmigona	compressa	41.461637	-81.172198	Geauga	West 14	1998	3	1
286	Lasmigona	costata	41.461637	-81.172198	Geauga	West 14	1998	7	3
287	Ligumia	nasuta	41.461637	-81.172198	Geauga	West 14	1998	7	8

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
288	Pyganodon	grandis	41.461637	-81.172198	Geauga	West 14	1998	46	64
289	Utterbackia	imbecillis	41.461637	-81.172198	Geauga	West 14	1998	7	3
290	Lampsilis	siliquoidea	41.461696	-81.165724	Geauga	West 15	1998	14	0
291	Lasmigona	complanata	41.461696	-81.165724	Geauga	West 15	1998	14	1
292	Lasmigona	compressa	41.461696	-81.165724	Geauga	West 15	1998	8	1
293	Lasmigona	costata	41.461696	-81.165724	Geauga	West 15	1998	14	0
294	Pyganodon	grandis	41.461696	-81.165724	Geauga	West 15	1998	107	1
295	Strophitus	undulatus	41.461696	-81.165724	Geauga	West 15	1998	4	0
296	Lampsilis	siliquoidea	41.454071	-81.160109	Geauga	West 16	1998	16	0
297	Lasmigona	compressa	41.454071	-81.160109	Geauga	West 16	1998	1	0
298	Lasmigona	costata	41.454071	-81.160109	Geauga	West 16	1998	1	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
299	Pyganodon	grandis	41.454071	-81.160109	Geauga	West 16	1998	31	10
300	Lampsilis	siliquoidea	41.446795	-81.155916	Geauga	West 17	1998	26	0
301	Lasmigona	complanata	41.446795	-81.155916	Geauga	West 17	1998	4	1
302	Lasmigona	costata	41.446795	-81.155916	Geauga	West 17	1998	1	0
303	Ligumia	nasuta	41.446795	-81.155916	Geauga	West 17	1998	1	0
304	Pyganodon	grandis	41.446795	-81.155916	Geauga	West 17	1998	30	10
305	Strophitus	undulatus	41.446795	-81.155916	Geauga	West 17	1998	1	0
306	Lampsilis	siliquoidea	41.443089	-81.152881	Geauga	West 18	1998	3	0
307	Lasmigona	complanata	41.443089	-81.152881	Geauga	West 18	1998	2	0
308	Ligumia	nasuta	41.443089	-81.152881	Geauga	West 18	1998	1	0
309	Pyganodon	grandis	41.443089	-81.152881	Geauga	West 18	1998	20	4

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
310	Pyganodon	grandis	41.468411	-81.123827	Geauga	Main 1 east	1985	0	1
311	Ligumia	nasuta	41.464021	-81.129116	Geauga	Main 2 east	1985	1	0
312	Anodontoides	ferussacianus	41.461215	-81.135897	Geauga	Main 3 east	1985	none	0
313	Pyganodon	grandis	41.442045	-81.151518	Geauga	Main 4 east	1985	p	1
314	Utterbackia	imbecillis	41.442045	-81.151518	Geauga	Main 4 east	1985	p	0
315	Lasmigona	complanata	41.437678	-81.152409	Geauga	Main 5	1985	p	0
316	Ligumia	nasuta	41.437678	-81.152409	Geauga	Main 5	1985	p	0
317	Pyganodon	grandis	41.437678	-81.152409	Geauga	Main 5	1985	p	0
318	Strophitus	undulatus	41.437678	-81.152409	Geauga	Main 5	1985	0	p
319	Lasmigona	complanata	41.424309	-81.156786	Geauga	Main 6	1985	p	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
320	Ligumia	nasuta	41.424309	-81.156786	Geauga	Main 6	1985	0	p
321	Pyganodon	grandis	41.424309	-81.156786	Geauga	Main 6	1985	p	0
322	Utterbackia	imbecillis	41.424309	-81.156786	Geauga	Main 6	1985	0	p
323	Lasmigona	complanata	41.418531	-81.162537	Geauga	Main 7 Bridge Ck	1985	7	0
324	Ligumia	nasuta	41.418531	-81.162537	Geauga	Main 7 Bridge Ck	1985	0	1
325	Pyganodon	grandis	41.409353	-81.158666	Geauga	Main 8	1985	0	1
326	Pyganodon	grandis	41.402885	-81.158253	Geauga	Main 9	1985	1	0
327	Lampsilis	siliquoidea	41.388141	-81.158172	Geauga	Main 10	1985	p	0
328	Lasmigona	complanata	41.388141	-81.158172	Geauga	Main 10	1985	p	0
329	Lasmigona	costata	41.388141	-81.158172	Geauga	Main 10	1985	0	p
330	Ligumia	nasuta	41.388141	-81.158172	Geauga	Main 10	1985	p	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
331	Pyganodon	grandis	41.388141	-81.158172	Geauga	Main 10	1985	p	0
332	Lasmigona	complanata	41.380799	-81.156805	Geauga	Main 11	1985	p	0
333	Pyganodon	grandis	41.380799	-81.156805	Geauga	Main 11	1985	p	0
334	Lampsilis	siliquoidea	41.375848	-81.15519	Geauga	Main 12	1985	0	p
335	Lasmigona	complanata	41.375848	-81.15519	Geauga	Main 12	1985	p	0
336	Lasmigona	costata	41.375848	-81.15519	Geauga	Main 12	1985	0	p
337	Pyganodon	grandis	41.375848	-81.15519	Geauga	Main 12	1985	p	0
338	Lampsilis	siliquoidea	41.365746	-81.161388	Geauga	Main 13	1985	0	p
339	Lasmigona	complanata	41.365746	-81.161388	Geauga	Main 13	1985	p	0
340	Lasmigona	costata	41.365746	-81.161388	Geauga	Main 13	1985	0	p
341	Ligumia	nasuta	41.365746	-81.161388	Geauga	Main 13	1985	0	p

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
342	Pyganodon	grandis	41.365746	-81.161388	Geauga	Main 13	1985	p	0
343	Utterbackia	imbecillis	41.365746	-81.161388	Geauga	Main 13	1985	p	0
344	Lampsilis	siliquoidea	41.351967	-81.163276	Portage	Main 14	1985	0	p
345	Lasmigona	complanata	41.351967	-81.163276	Portage	Main 14	1985	p	0
346	Lasmigona	costata	41.351967	-81.163276	Portage	Main 14	1985	0	p
347	Pyganodon	grandis	41.351967	-81.163276	Portage	Main 14	1985	p	0
348	Lampsilis	siliquoidea	41.325308	-81.172877	Portage	Main 15 camp hi	1985	p	0
349	Lasmigona	complanata	41.325308	-81.172877	Portage	Main 15 camp hi	1985	p	0
350	Lasmigona	compressa	41.325308	-81.172877	Portage	Main 15 camp hi	1985	p	0
351	Lasmigona	costata	41.325308	-81.172877	Portage	Main 15 camp hi	1985	p	0
352	Ligumia	nasuta	41.325308	-81.172877	Portage	Main 15 camp hi	1985	p	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
353	Pyganodon	grandis	41.325308	-81.172877	Portage	Main 15 camp hi	1985	p	0
354	Strophitus	undulatus	41.325308	-81.172877	Portage	Main 15 camp hi	1985	p	0
355	Utterbackia	imbecillis	41.325308	-81.172877	Portage	Main 15 camp hi	1985	0	p
356	Lampsilis	siliquoidea	41.31689	-81.189716	Portage	Main 16	1985	p	0
357	Lasmigona	complanata	41.31689	-81.189716	Portage	Main 16	1985	p	0
358	Lasmigona	compressa	41.31689	-81.189716	Portage	Main 16	1985	p	0
359	Ligumia	nasuta	41.31689	-81.189716	Portage	Main 16	1985	p	0
360	Pyganodon	grandis	41.31689	-81.189716	Portage	Main 16	1985	p	0
361	Lampsilis	siliquoidea	41.304444	-81.197953	Portage	Main 17	1985	p	0
362	Lasmigona	complanata	41.304444	-81.197953	Portage	Main 17	1985	p	0
363	Lasmigona	costata	41.304444	-81.197953	Portage	Main 17	1985	p	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
364	Ligumia	nasuta	41.304444	-81.197953	Portage	Main 17	1985	p	0
365	Pyganodon	grandis	41.304444	-81.197953	Portage	Main 17	1985	p	0
366	Strophitus	undulatus	41.304444	-81.197953	Portage	Main 17	1985	p	0
367	Lampsilis	siliquoidea	41.289121	-81.212641	Portage	Main 18	1985	p	0
368	Lasmigona	complanata	41.289121	-81.212641	Portage	Main 18	1985	p	0
369	Lasmigona	compressa	41.289121	-81.212641	Portage	Main 18	1985	p	0
370	Lasmigona	costata	41.289121	-81.212641	Portage	Main 18	1985	p	0
371	Ligumia	nasuta	41.289121	-81.212641	Portage	Main 18	1985	p	0
372	Pyganodon	grandis	41.289121	-81.212641	Portage	Main 18	1985	p	0
373	Strophitus	undulatus	41.289121	-81.212641	Portage	Main 18	1985	p	0
374	Lampsilis	siliquoidea	41.278769	-81.221042	Portage	Main 19	1985	1	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
375	Lasmigona	complanata	41.278769	-81.221042	Portage	Main 19	1985	0	p
376	Lasmigona	compressa	41.278769	-81.221042	Portage	Main 19	1985	1	0
377	Lasmigona	costata	41.278769	-81.221042	Portage	Main 19	1985	0	p
378	Pyganodon	grandis	41.278769	-81.221042	Portage	Main 19	1985	0	p
379	Lampsilis	siliquoidea	41.270585	-81.240912	Portage	Main 20	1985	p	0
380	Lasmigona	complanata	41.270585	-81.240912	Portage	Main 20	1985	p	0
381	Lasmigona	costata	41.270585	-81.240912	Portage	Main 20	1985	p	0
382	Pyganodon	grandis	41.270585	-81.240912	Portage	Main 20	1985	p	0
383	Strophitus	undulatus	41.270585	-81.240912	Portage	Main 20	1985	p	0
384	Lampsilis	siliquoidea	41.258117	-81.259376	Portage	Main 21	1985	p	0
385	Lasmigona	complanata	41.258117	-81.259376	Portage	Main 21	1985	p	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
386	Lasmigona	compressa	41.258117	-81.259376	Portage	Main 21	1985	0	p
387	Lasmigona	costata	41.258117	-81.259376	Portage	Main 21	1985	p	0
388	Ligumia	nasuta	41.258117	-81.259376	Portage	Main 21	1985	p	0
389	Pyganodon	grandis	41.258117	-81.259376	Portage	Main 21	1985	p	0
390	Strophitus	undulatus	41.258117	-81.259376	Portage	Main 21	1985	p	0
391	Lampsilis	siliquoidea	41.250035	-81.265792	Portage	Main 22	1985	p	0
392	Lasmigona	complanata	41.250035	-81.265792	Portage	Main 22	1985	p	0
393	Lasmigona	compressa	41.250035	-81.265792	Portage	Main 22	1985	p	0
394	Lasmigona	costata	41.250035	-81.265792	Portage	Main 22	1985	p	0
395	Ligumia	nasuta	41.250035	-81.265792	Portage	Main 22	1985	p	0
396	Pyganodon	grandis	41.250035	-81.265792	Portage	Main 22	1985	p	0

code	Genus	Species	Latitude	Longitude	County	Locality	Collected	live	shells
397	Strophitus	undulatus	41.250035	-81.265792	Portage	Main 22	1985	p	0
398	Lampsilis	siliquoidea	41.246115	-81.284718	Portage	Main 23	1985	p	0
399	Lasmigona	complanata	41.246115	-81.284718	Portage	Main 23	1985	0	p
400	Lasmigona	compressa	41.246115	-81.284718	Portage	Main 23	1985	p	0
401	Ligumia	nasuta	41.246115	-81.284718	Portage	Main 23	1985	p	0
402	Pyganodon	grandis	41.246115	-81.284718	Portage	Main 23	1985	p	0
403	Strophitus	undulatus	41.246115	-81.284718	Portage	Main 23	1985	p	0