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Freshwater Mussel Populations of the Monongahela River, PA and Evaluation of the ORSANCO Copper Pole Substrate Sampling Technique Using G.I.S. Interpolation with Geometric Means

Jonathan Hart
jhart41983@gmail.com

FRESHWATER MUSSEL POPULATIONS OF THE MONONGAHELA RIVER, PA AND EVALUATION OF THE ORSANCO COPPER POLE SUBSTRATE SAMPLING TECHNIQUE USING G.I.S. INTERPOLATION WITH GEOMETRIC MEANS

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Jonathan Hart

Committee Members:
Dr. Thomas G. Jones. Ph.D., Committee Chairperson
Dr. Mindy Yeager Armstead, Ph.D., Committee Member
James Spence, M.S., Committee Member

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I would like to dedicate this thesis to my mother and father. Their emotional support and guidance are forever indebted within my heart. To my friends and loved ones who watched over me with patience and understanding through long hours of reassurance and distinction which helped me to achieve my educational goals.

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ABSTRACT

Large river studies for freshwater mussel populations and habitat in the Monongahela River within Pennsylvania have been almost non-existent over the past century. Aquatic diversity and water quality have been impaired in the Monongahela River since the Industrial Revolution and early impoundments were constructed to control the river. To date, there have been no thorough mussel population studies conducted on the Pennsylvanian Monongahela River proper since A.E. Ortmann in 1919. The mussel population accounts for this large river system are invaluable accounts of the aquatic condition of the Monongahela River. Mussel populations and habitat within the river have diminished drastically during the 20th century. Mussel populations and habitat were evaluated using SCUBA reconnaissance at 31 survey sites over 91 river miles. Survey methods included timed SCUBA searches for mussel populations and substrate consistency. Substrate habitat at each site was evaluated using diver reconnaissance and a modified version of the Ohio River Valley Water Sanitation Commission (ORSANCO) Copper Pole Substrate Sampling Protocol. Substrate sampling efficacy using the Copper Pole sampling technique was evaluated using benthic diagrams built using Inverse Distance Weighting with software ArcGIS 9.2. Results of this survey indicated seven (7) mussel species persist within the river with limited abundance compared to the 28 species accounted for in 1919. Habitat assessment techniques evaluated for use in large rivers illustrated an overestimation of substrate size. Paired T-test and Wilcoxon Signed-Rank analysis of Copper Pole Sampling versus diver reconnaissance of substrate size classes expressed significant differences of substrate geometric means. These data are presented to build on the ever growing research and evaluation of techniques used for large river ecosystem monitoring currently being developed in the field of river ecology.

Keywords: Monongahela River, Unionidae, bivalve, habitat, ORSANCO, substrate, geometric mean, large river, Interpolation, biomonitoring

1. CHAPTER I: Freshwater Mussel Populations and Habitat of the Monongahela River, Pennsylvania

1.1 INTRODUCTION

An evaluation of the mussel populations and substrate habitat of the Pennsylvanian Monongahela River was conducted in 2008 to enhance the knowledge of the rivers aquatic fauna and ecosystem. The study was conducted by the Marshall University Aquatic Ecology Laboratory directed by Dr. Tom Jones in cooperation with the Marshall University College of Science Department of Integrated Science & Technology. The objective of the study was to perform a thorough evaluation of the river's freshwater mussel community as well as habitat condition across the 91 miles of the Monongahela River located within Pennsylvania. The key purpose of this survey was to accurately identify the number of freshwater mussel species as well as the quality of habitat available in the Monongahela River within Pennsylvania. Further purposes of this study were to evaluate the efficiency of a modified version of the Ohio River Valley Water Sanitation Commission (ORSANCO) substrate sampling protocol known as Copper Pole Sampling. Data such as this are invaluable sources of information that are pertinent to regulatory agencies, environmental groups, and the concerned citizens of Pennsylvania for the continued conservation and monitoring of the river biota. Thirty-one Survey sites, each approximately 500 meters in length, were randomly selected across 91 river miles to accurately assess the river ecosystem. Survey sites were designated to either left descending bank (LDB) or right descending bank (RDB) to avoid interference with commercial navigation on the river. Survey sites at each river station were divided into channel, channel slope, and bank habitats to evaluate available habitat for mussel colonization.

1.2 BACKGROUND

Freshwater mussels are found worldwide and consist of the Family Margaritiferidae and Unionidae. The greatest accumulation of species is located in North America and consists of 297 recognized taxa including 281 species and 16 subspecies (Williams et al., 1993). Of these 297 species 35 have gone extinct since 1900 (Nedeau, Smith and Stone 2005). In the last 30 years mussel populations have taken a dramatic decline in numbers. The Nature Conservancy has registered 55% of North America's mussels as extinct or imperiled (Williams et al., 1993). The American Fisheries Society lists 21 taxa as endangered or possibly extinct and 77 taxa endangered, making freshwater mussels the most endangered freshwater faunal group in North America (Williams et al., 1993). Mussel populations have been declining at an extinction rate of 1.2% per decade since 1900. Without effective conservation and immediate action it has been estimated that the extinction rate will increase to 6.4% per decade eradicating 127 imperiled mussel species. (Ricciardi and Rasmussen, 1999).

Mussels are not the only groups endangered in North America as fish, crayfish, gastropods, amphibians and birds are also projected to have further increases in extinction rates (Ricciardi and Rasmussen, 1999). These increasing extinction rates are a clear sign that the waterways of North America are imperiled. The alarming faunal decline recognized in the last 30 years has been linked primarily to habitat degradation as a result of anthropogenic activities (Williams et al., 1993). These disturbances include but are not limited to, dam construction, stream channelization, pollution, siltation, or altered stream flow patterns. As suitable habitat is destroyed and populations decline a very real threat of extinction becomes apparent.

As the integrity of rivers in North America gradually declines greater emphasis must be placed upon the conservation and study of our remaining mussel populations. The life cycle and sedimentary habitat of freshwater mussels makes them an ideal ecological monitor for river health (Dennis 1971). In many streams across North America mussels are extremely prevalent with quantities reaching 10 to 100 mussels per square meter with biomasses ranging from 5 to 100 grams dry matter. These very prevalent lotic organisms play key roles in particle processing, nutrient cycling, and sediment mixing (Strayer et al., 2004). Mussels are a significant part of the aquatic food chain by providing food directly to higher trophic levels while also providing nutrients to lower trophic levels with the processing and formation of pseudofeces (Hart 1995). The high volume of water processed by mussels makes them an integral part of the chemical processes in the water column. The water that is siphoned into and out of the mussel is filtered providing the mussel with food while also removing and temporarily retaining particular chemicals and heavy metals from the environment. This filtering process gives mussels an important role in biological water purification (Hart 1995). Mussels also are an important prey item for particular species of organisms such as the muskrat (*Ondatra zibethica*), the mink (*Mustela vison*), the otter (*Lutra canadensis*), as well as several species of fish (Hart 1995).

1.2.1 History

Original interest in freshwater mussels was brought to light in the 1800s with the propagation of the pearl button industry. In 1912, there were 196 manufacturing plants using freshwater mussel shells to produce pearly buttons (Dennis 1971). By 1930, the mussel industry drastically declined with the invention of the plastic button. Since this time, freshwater mussel shells have been utilized by the Japanese cultured pearl industry. Certain species of shell, those only found in freshwater, provide the proper texture and hardness to produce manmade valuable pearls. By artificially placing ground spheres of freshwater shell under the mantle of a clam or oysters, the mantle produces a pearly nacre which eventually forms into a pearl. The quality of shell needed to produce commercial quality pearls to date can only be found in the interior basin of the United States and certain rivers in China (Dennis 1971).

Early mussel harvesting took a moderate toll on mussel populations but the most serious reason behind mussel declines to date is habitat destruction by anthropogenic activities. These effects caused mainly by civilization include agriculture, impoundments, dams, dredging, pollution, or sedimentation (Way et al., 1990), all of which permanently alter the habitat where freshwater mussels survive.

The modification of free flowing rivers by dam construction has dramatically altered the natural state of North American rivers. These dams or impoundments, built for numerous reasons including navigation, flood control, reservoirs, recreation, etc., have permanently altered the habitat and environment available to freshwater mussels (Watters 2000). River impoundments turn free-flowing rivers into lacustrine environments. These lacustrine environments have increased sedimentation rates and depth while decreasing bottom temperatures (Watters 2000). Mussel decline and elimination of species from numerous rivers have been directly attributed to increased sedimentation (Way et al.,. 1990); (Stansberry 1970). The conditions created by dams within the physical environment often become unsuitable for juvenile mussel settlement (Fuller 1974).

1.2.2 Life Cycle

The many factors affecting the reproductive survival of freshwater mussels are poorly understood and have received heavy scientific interest (Moles and Layzer 2008). The life cycle of a mussel begins as an egg in the ovaries of the female. As spawning begins, the eggs are transferred to specialized chambers known as marsupial gills and these gills begin to inflate. Males release sperm into the water column known as broadcast spawning. The siphoning females uptake the sperm and fertilize their eggs. The embryos will develop into larvae known as glochidia within the female's marsupial pouches. The female mussels are referred to as "gravid" during this brooding period. From mechanisms that are not fully understood, the female will spontaneously expel the glochidia into the water column. In order to survive the glochidia must attach or encyst to the gills of a suitable fish host. The glochidium feeds off of the fishes gills and once mature, the juvenile mussel expels itself from the gills onto the substrate for settling (Moles and Layzer 2008). Any number of disruptions can occur to its life cycle at any stage resulting in recruitment failure.

The known vertebrate hosts in all but one species of mussels are fish and their corresponding gills. The fish hosts are an essential stage of development for the mussel. Each mussel species has particular species of fish which they utilize for survival. The fish hosts are essential to the reproduction of particular mussel species and therein can be a limiting factor in the mussel distribution or existence (Watters 1996). One of the major problems affecting fish host availability are the impoundments and dams restricting the natural flow of water and ultimately the ability of fish to travel through the river system. The availability of proper fish hosts to mussel populations is as limiting to population abundance and distribution as glochidia substrate settlement (Way et al.,1990). Freshwater mussels are then influenced by these waterway barriers in an equal factor as the corresponding fish hosts are (Watters 2000).

1.2.3 Impoundments

A vast number of freshwater mussels live in and prefer free flowing waterways. Brown and Banks (2001) state that impoundments are the greatest threat imposed on unionid mussels today. The rivers of North America have been heavily modified with over 550 large waterway dams. In the United States there are nearly twice as many as there are in Canada, South and Central America combined (Pringle et al., 2000). In the United States 17% of the 5.6 million kilometers of river were dammed during the twentieth century. Major impoundment development peaked during the 1960’s with almost 30 dams constructed each year (Pringle et al., 2000). The effects of dams on fish populations and their upstream migrations are heavily documented. Many native stocks of certain taxa such as salmonids, shads, herrings, sturgeons, freshwater shrimp, suckers, minnows, darters and even the American eel have been extirpated from their native headwater reaches and diminished in population by migration impediment from these impoundments (Pringle et al., 2000).

The reservoirs and tailwaters created from these impoundments have altered the native assemblages that were dependent on lotic environments. The river environment upstream of the dam becomes inundated with water, diminishing habitat, while increasing siltation and anoxic conditions in the hypolimnion (Moles and Layzer 2008). Directly downstream of the dam, releases of hypolimnetic water deplete dissolved O_2 concentration. These alterations along with altered thermal regimes can inhibit gametogenesis and invertebrate reproduction. In 2001, Hardison and Layzer found that below three dams, mussel densities were negatively correlated to the discharge shear stress and hypothesized that higher stresses found during spring floods inhibited settlement of juvenile mussels (Hardison and Layzer 2001). During periods of high flow the ability of sperm to be transported to distant females is reduced by the high water volume, suggesting that many rivers with a large connectivity of dams may not have adequate recovery periods between dams, severely affecting macroinvertebrate populations (Moles and Layzer 2008). However, though specific testing of this has been difficult based on the various factors associated with mussel reproduction.

Impoundment has led to an emergence of species flourishing, both native and non-native, which prefer the lentic water column settings created by these dams (Pringle et al., 2000). At the turn of the twentieth century, rivers were being quickly converted from free-flowing to run-of-river reservoirs, and caused almost full elimination of riffle inhabiting mussels from the genera *Pleurobema*, *Plethobasus*, and *Epioblasma* (Miller and Payne 1998). This flow impedance has caused an overwhelming change in mussels species established in North America's rivers. Rivers that were once free flowing with many riffle series were impounded into reservoirs, with reduced water velocity and ever increasing sedimentation rates. This has led to the emergence of many large rivers having an overwhelmingly dominant population of lentic tolerant species of *Quadrula* and *Amblema plicata* (Miller and Payne 1998). Numerous studies have documented the decline in mussel species below impoundments. The effects of these impoundments is easily seen in altered flow and temperature regimes, changed patterns of sedimentation and scour, and in the transport of particulate organic matter (Vaughn and Taylor 1999).

1.2.4 Sedimentation/Siltation

The rivers that were once a series of shallow shoals and runs were impounded to allow commercial vessels ease of transport. The Monongahela River is maintained at a minimum depth of 9 feet to allow passage of these vessels. As vessels proceed, they create pulses of turbulence and elevate suspended solids. The effect of this turbulence is unconsolidated silt and sand, which is very poor substrate for invertebrates. Substrate instability has been shown to be a limiting factor affecting mussel beds in the Ohio River drainage (Miller and Payne 1998).

In order to maintain commercial barge channels the rivers are dredged periodically. The dredging not only removes the previous substrate, destroying any potential habitat, but also removes any invertebrates that may have been established. The effect of sedimentation from increased dredging has been shown unsatisfactory attention. The U.S. Environmental Protection Agency established that in order to maintain satisfactory biota in streams that turbidity should remain below 50 Nephelometic Turbidity Units and/or 50ppm (Meador and Layher 1998).

Increased sedimentation in a river can be extremely destructive to mussel fauna from scouring and smothering. In 1970, James Gammon reported a 40% reduction in macro-invertebrate population below a rock quarry discharging inorganic sediment (Gammon 1970). Scouring and suspended materials in water columns severely injure both the gills of fish and mussels, as well Unionid mantles and shells (Wolcott 1990). Silt levels above 1,000 mg/l have been shown to inhibit food uptake of freshwater mussels by as much as 80% (Wolcott 1990).

The overall effects of siltation on mussel populations have been documented since the early 20th century. Robert Coker in 1914 noted the inherent demise of mussel species as impoundments increased siltation and favored species which preferred lentic conditions (Coker 1914). Extended periods of high siltation have shown to effect mussel metabolisms, switching from siphoning proteins from the water column to depleting non-protein body stores for energy (Wolcott 1990). The smothering effects of siltation in 1936 devastated mussel populations in the Tennessee, Ohio, and Mississippi Rivers (Dennis 1984). As little as ¼ to 1 inch of siltation has been shown to cause mortality in freshwater mussels (Ellis 1936).

1.2.5 Gravel Mining/Dredging

The most widespread and persistent threat to mussel populations is gravel mining (Brown and Banks 2001). Sand and gravel are essential components used in construction. The need for such materials has given rise to aggressive mining of America's waterways for industrial purposes. Proponents of this industry highly emphasize the need for materials as well the benefits of maintaining the shipping channels. These activities inherently reduce the suitable habitat for macro-invertebrates (Brown et al., 1998). As the larger particles of substrate are removed from the river, large quantities of sediments are released increasing the river's turbidity and altering the normal flow of the water channel. Further effects arise as the newly exposed sediment, without larger particle sizes shielding shear force, erode quickly and increase sediment load. After dredging operations are complete, large populations of freshwater mussels are often found spoiled on the banks. These mussels represent the largest part of the total biomass in the alluvial environment and are key components in the filtering of large volumes of water which play vital roles in modifying the phytoplankton community (Aldridge 2000). Monahan and Caffrey (1996) estimated that as many as 1 million macroinverterbrates were removed for every one ton of sediment extracted (Monahan and Caffrey 1996).

Further impacts are seen as the mining and dredging activities increase channel degradation and erosion in an upstream direction known as headcutting. Headcutting causes dramatic stream bank erosion and incises the river ultimately narrowing and straightening the river further reducing the habitat and vegetation associated with the river bank. This erosion adds increased risks for floods and reduces bank stability (Meador and Layher 1998)

1.2.6 Substrate

The biotic and abiotic habitat characteristics suitable for mussels are poorly understood (Brim Box et al., 2002). A primary influence on mussel distribution is the type of substrate present in a system. Substrate composition has been shown to be a heavy influence on mussel community locations. It has also been shown that, in addition to substrate type, substrate stability has a major influence on mussel locations (Brown and Banks 2001). Brown and Banks (2001) found that many mussel species that had been previously reported by Brim Box and Mossa (1999) as silt intolerant were in fact quite commonly found in silt, illustrating that sediment may not be as large of an influence as the adjusted flow. However, it is overwhelmingly seen that mussel populations are much more commonly found in coarser sediments where dislodgement is less likely. Mussels found in large particle-size substrates and gravel bars may then be considered taking advantage of the stable habitat while gaining shelter from turbidity and scouring (Brown and Banks 2001)(Brim Box et al., 2002).

Habitat preferences by mussels have been attributed to species preferences as well. Shell shape, density, and morphology have been noted as strong factors governing species-to-habitat relations. Species with thick shells consequently inhabit abrasive environments where scour and erosion are more common. Thin shelled species lack these protections and are often found in softer environments such as silt or mud layers allowing for ease of movement and buoyancy in the soft alluvium. Evidence to this is easily seen in historically reported mesohabitats such as mud or sand where common species found could include representatives of the genera *Villosa*, *Toxolasma*, *Pyganodon* or *Potamilus* (Gagnon et al., 2006).

1.2.7 Mining

Further impacts to the mussel fauna within the Monongahela River Drainage are the long term effects of coal mining. Of the numerous anthropogenic sources of stress to freshwater mussels, coal mining is seen as one of the most severe (Diamond and Serveiss n.d.). Besides the well documented effects such as sedimentation, acid mine drainage with heavy metals, and the associated water quality degradation, there exists further impacts to aquatic fauna from the production of coal from unprocessed coal known as coal fines.

Elevated levels of toxic contaminates within sediments and substrate have been associated with coal mining and affiliated coal ash. These contaminated sediments have been shown to decrease growth and survival rates as contaminate levels increase (Kunz and Ingersoll 2010).

Levels of As, Se, Sr and Cu have been commonly shown to occur in biota associated with coal mining. Accumulations of Cd, Se and Sr have been shown to bioaccumulate within the biota as sediment levels increased (Williams and Taylor 2006). Mining activities and their runoff release sediments, salts, and other pollutants into waterways as well as increased water volumes. Mussel community compositions in these areas have been shown to result in communities which favored more pollution tolerant species which were less habitat-specific (Watters 2000).

1.2.8 Study Area

The study area for this survey was the Monongahela River within western Pennsylvania. Western Pennsylvania has a long industrial history which has come with severe consequences to the rivers and environment. The Allegheny Divide splits the state of Pennsylvania into two basins, either draining ultimately into the Mississippi River or the Atlantic Ocean (Dennis 1971). The Monongahela River is one of the largest drainage basins within Pennsylvania, draining approximately 19,011km^2 into the Ohio River.

The Monongahela begins in Fairmont, West Virginia, by the confluence of the West Fork and Tygart Rivers and drains parts of West Virginia, Pennsylvania, and Maryland. The river flows north from West Virginia into Pennsylvania terminating in the Ohio River. The rivers total length is 127 miles, of which 91 miles are within Pennsylvania (Rowe 1997)(Sams and Beer 2000). Two major rivers that join the river are the Cheat and Youghiogheny rivers, joining at Point Marion and McKeesport, PA, respectively. At the Pennsylvania border the average discharge from West Virginia is approximately 212,000 m^3/second. There are 9 lock and dams on the river, 6 of which are in Pennsylvania (Rowe 1997).

The eastern and southwestern portion of the drainage lays at an elevation between 975 to 1375 feet above sea level. It is composed of mountainous layers of lower Pennsylvanian, Devonian, and Mississippian (375mya) rock layers. The rugged and tilted nature of the strata gives rise to series of parallel ridges producing high-gradient headwater streams in a trellis pattern. The western area of the drainage is composed of primarily sandstone and shale in horizontal layers with intermittent seams of Pennsylvanian (345 mya) and Permian (280mya) coal. This portion has primarily low gradient streams with a tendency to form dendritic patterns (Rowe 1997).

1.3 METHODS OF INVESTIGATION

Mussel surveys were conducted using timed linear transects via SCUBA divers. A total of 31 sampling locations each approximately 500m in length were investigated over the 91 miles of Monongahela River located in Pennsylvania (FIGURE 1)(TABLE 1). Each river sampling site was surveyed on either the left descending bank or right descending bank. Each river site was surveyed with 12 randomly selected dives at timed intervals of five minutes each. Transects were made in parallel with the shore and flow, oriented in the upstream direction to maximize visibility. The 12 dives at each river site were split to include four random dives in less than ten feet of water and eight dives random across the survey sites channel slope and channel bottom habitats. The bank habitats were defined as shallow areas between the depths of 1-10 feet.

The large river system presented a well defined slope that was readily distinguishable dropping from the bank depths, often at a near 45 degree angle, into the leveled channel bottom (FIGURE 2). Channel habitats were defined from the point where the slope angle became horizontal to the center of the river or mid-channel. A boat mounted depth finder was used to assess channel depths in order to ascertain depths less than ten feet for shallow water dive transects. The maintained barge channel provided a very even contour layout throughout the river system. Only few areas presented differing contour depths and dives were adjusted to still maintain habitat delineations. At areas where the diver encountered obstacles such as point or gravel bars, the transect was adjusted to stay within habitat depth requirements. Obstacles that required divers to alter direction in this manner were seldom encountered during the survey. This provided equal habitat surveying to avoid missing shallow or deep water mussel communities. Dives performed in parallel with the shore and river channel ensured minimal conflict with commercial and recreational traffic. All dives were required to be greater than 100 meters from any intake structures or potential hazards such as mooring docks. No dives were performed between the lock chamber mooring points and the lock and dam structure.

Sample sites were located using a Garmin GPSMap 498 at coordinates provided from the Pennsylvanian Department of Environmental Protection (FIGURE 3). Upon reaching the site, the transects were randomly placed throughout location between 250 meters up and downstream of the coordinates, totaling 500m at each river site location. This ensured that the sample site would be adequately sampled over a variety of habitats, depths, and locations. Transect locations were kept at a minimum of five meters apart in any direction. At each dive site, a safety diver deployed an anchor which served as the beginning mark of the transect. Divers recorded an upstream compass heading before entering the water and maintained this orientation using a dive compass. Transect lengths were obtained from a 250 foot dive reel which was marked at 1 meter increments and attached to the anchor line. Divers were in constant communication at all times by remote dive com communication gear built into the SCUBA dive helmet system. The search area width of each transect was one meter wide total. Divers searched visually and tactilely at the substrate surface only. Large rocks encountered during the transect were turned over and searched beneath. The substrate was not disturbed or searched, making the protocol a consistent surface search only for time efficiency. At the end of five minutes, divers recorded on a wrist dive slate substrate composition percentages for fines, sand, gravel, cobble, boulder, and bedrock. Zebra mussel occurrence was ranked on a 1-5 scale: 1 = 1 individual; 2 = multiple individuals; 3 = small clumps of individuals; 4 = greater than 50% coverage and, 5 = complete coverage of substrate. The substrate categories were defined as follows: Fines = .001-.062mm; Sand = .063-2.0mm; Gravel = 2.0-64mm; Cobble = 64.0-

256.0mm; Boulder = 256.0-4096.0mm; and Bedrock = 4096.0- 8000.0+mm. Average depth was recorded by the diver as well as by dive vessel.

FIGURE 1. Location map of Monongahela River within Pennsylvania and West Virginia.

http://www.wvpubcast.org/

FIGURE 2. River Habitats sampled by divers during Monongahela Mussel Survey 2008.

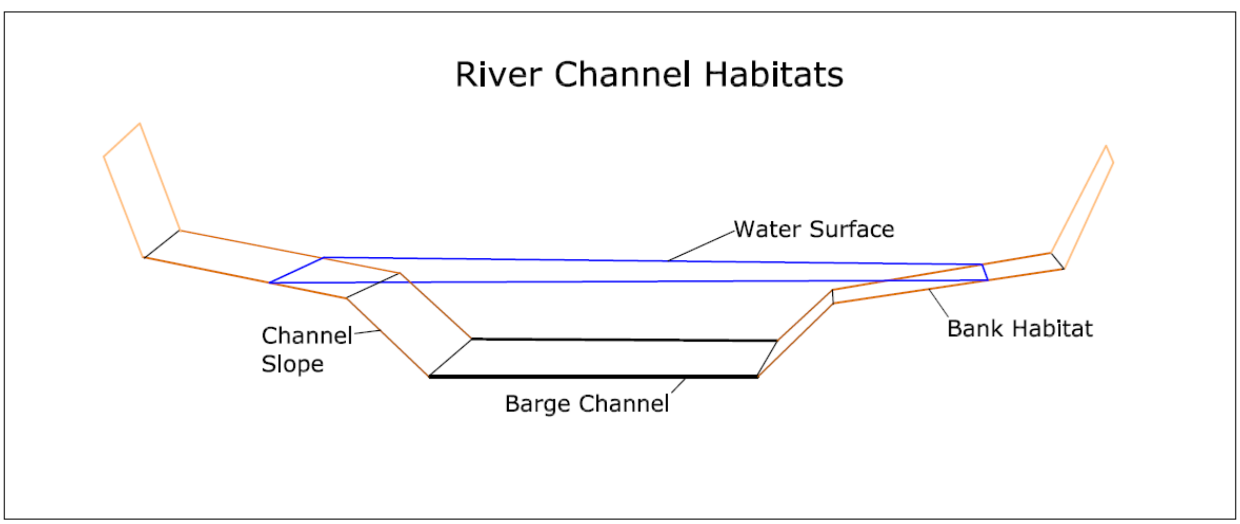


FIGURE 3. Location map of sampling site locations along the Monongahela River, PA.

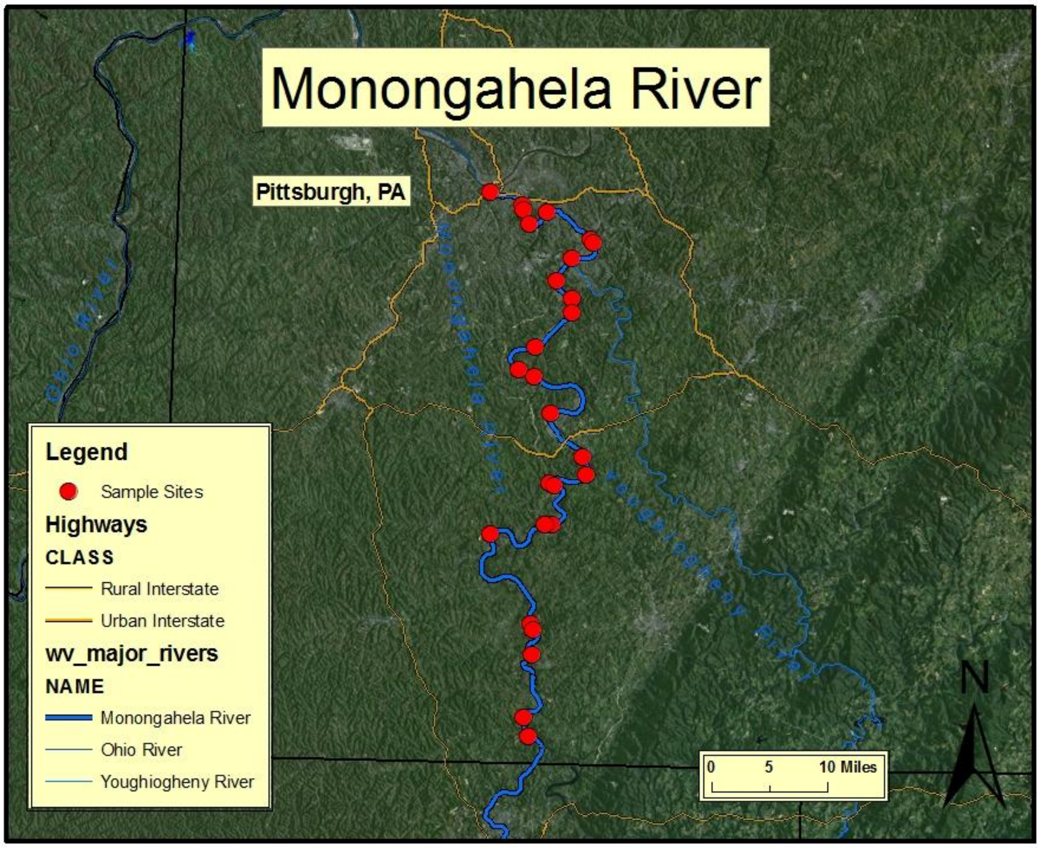
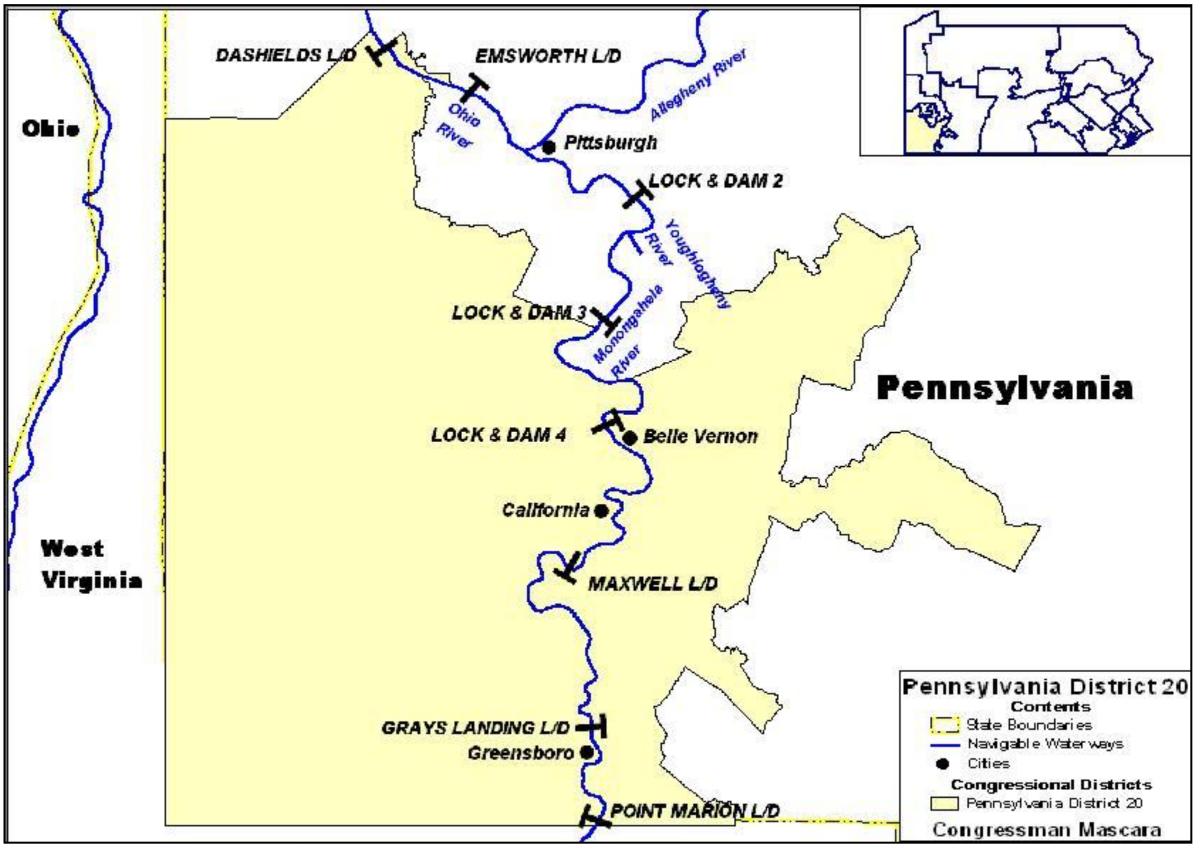
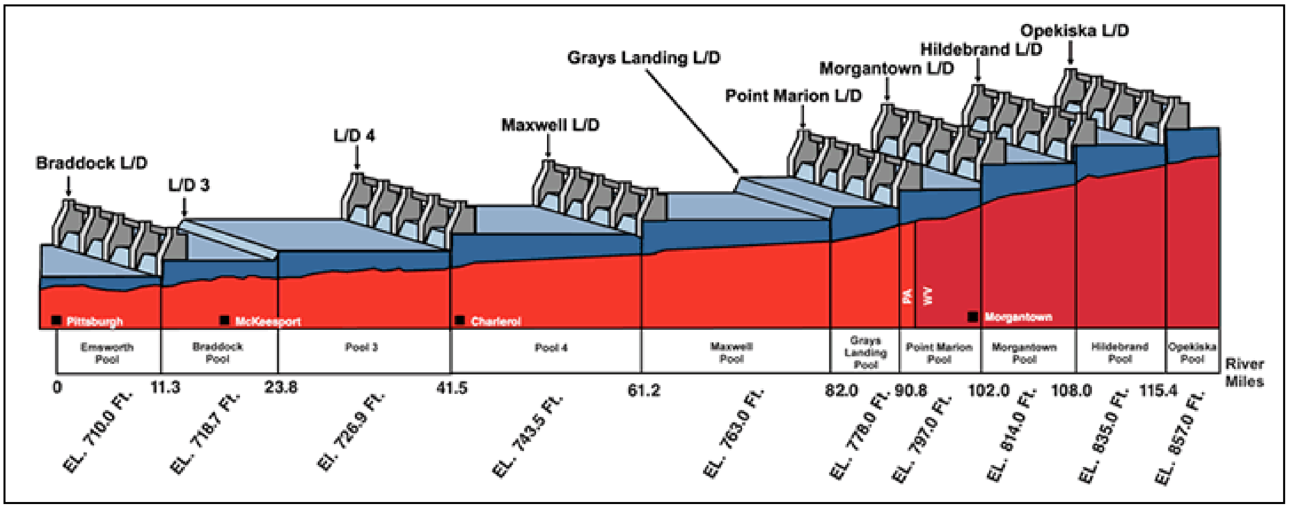


FIGURE 4. Location map of Monongahela River with Pennsylvania and corresponding lock and dam systems.



(U.S. Army Corps of Engineers, 2010)

FIGURE 5. Map of lock and dam systems in place within the Monongahela River between Pennsylvania and West Virginia.



(U.S. Army Corps of Engineers, 2010)

1.4 RESULTS

The 2008 study collected 148 live mussels across the 31 survey sites (TABLE 3). This represented seven species of mussels: *Amblema plicata* (threeridge); *Lampsilis siliquoidia* (fatmucket); *Lasmigona costata* (fluted shell); *Leptodea fragilis* (fragile papershell); *Potamilus alatus* (pink heelsplitter); *Pyganodon grandis* (giant floater); *Quadrula quadrula* (maple leaf). Of the 148 mussels found, *Potamulis alatus* represented 91.2% of the total abundance with 135 individuals at 24 of the 31 sites. The second most common mussel found was *Lampsilis siliquoidia* with seven individuals representing 4.7% of the total abundance from 6 of the 31 sites sampled. Two individuals of *Quadrula quadrula* were found at sites 4 & 9. One individual was found of each of the following: *Lasmigona costata*, *Leptodea fragilis*, *Pyganodon grandis*, and *Amblema plicata* (FIGURE 4 & 5). The 31 survey sites accounted for 373 separate dive transects with 31.1 underwater man-hours total. The five minute transect dives surveyed 12,977 square meters of river substrate and had a mean area of 34.7 m^2 with a standard deviation of 11.2. Survey dive transects had a mean depth of 12.5 feet with a standard deviation of 6.9. The mean square meters per site surveyed was 418.6m^2 with a standard deviation of 90.1 (TABLE 3). The 31 survey sites were located in six “pools” of the Monongahela River within Pennsylvania, with a “pool” being considered the corresponding river length between two lock and dams. Substrate survey results are discussed in the following chapter. The following is a summary of the mussel survey results by pool.

1.4.1 Results by River Pool

The Monongahela has ten pools corresponding with the ten lock and dams along the river system. Pools are named by the downstream or retaining lock below. In Pennsylvania there are six pools in 91 miles of the Monongahela's total 128 miles of river (FIGURE 4). The Monongahela's first pool from downstream towards upstream is the Emsworth Pool. This pool, named after the Emsworth Lock and Dam, is located at mile 6.2 of the Ohio River. The confluence of the Allegheny and Monongahela Rivers at Mile 0 of the Monongahela, is the beginning of the Ohio River. The Braddock Lock and Dam begins at mile 11.2. At river mile 23.8 at Elizabeth, Pennsylvania, Pool 3 begins and is correspondingly named "Pool 3" after the Lock & Dam 3. At mile 41.5 at Charleroi Pennsylvania, Pool 4 begins and is also correspondingly named after Lock & Dam 4. The Maxwell Pool starts at river mile 61.2 approximately five miles downstream from Brownsville, PA. At river mile 82.0, the Grays Landing Pool begins near the town of Grays Landing. This pool is 8.8 miles long and ends at the Point Marion Lock & Dam at river mile 90.8 which is 0.2 miles from the West Virginia border. Due to the very small length of Point Marion Pool being located in Pennsylvania, there were no sites in this pool (FIGURE 5).

1.4.2 Emsworth Pool

The Emsworth Pool is 17.4 miles long containing the Allegheny, Monongahela, and Ohio Rivers (FIGURE 35). There are 11.2 miles of the Monongahela River in this pool. Sites 1-5 were located within this pool. A total of 1,465 square meters were surveyed with an average site search area of 293 m^2 and an average dive length of 24.4 meters. The average site depth was

13.4 feet deep. The mean mussel density of this pool was 0.013 mussels per square meter from the five sites surveyed. Nineteen live mussels were found representing six different species: 14 pink heelsplitters (*Potamils alatus*); one fluted shell (*Lasmigona costata*) ; one fragile papershell (*Leptodea fragilis*); one giant floater (*Pyganodon grandis*); one mapleleaf (*Quadrula quadrula*) and, one fat mucket (*Lampsilis siliquoidea*). Fourteen of the pink heelsplitter mussels (*P. alatus*) collected were within sites 2-5. At site 1, one fragile papershell mussel (*L. fragilis*) was found, and represented the only mussel found at this site. At Site 2, one fluted shell mussel (*L. costata*) was collected. At site 3, seven pink heelsplitter mussels were found and represented the only species collected. At site 4, one giant floater (*P. grandis*), and one maple leaf mussel (*Q. quadrula*) was found. Three pink heelsplitters were also found at Site 4. At site 5, one fat mucket mussel (*L. siliquoidea*) and one pink heelsplitter mussel (*P. alatus*) were found. The mussel density in the Emsworth Pool from these five sites was found to be 0.013 mussels per m^2, the second highest found during this survey. Forty-three of the 60 dives made in the Emsworth Pool reported no zebra mussel (*D. polymorpha*) activity. Ten dives reported seeing one zebra mussel within the Emsworth pool and seven dives reported seeing two or more individual zebra mussels (TABLE 2). Zebra mussel means per site, based on the 1-5 ranking method, were as follows: Site 1-0.333; Site 2- 0.167; Site 3- 0.833; Site 4- 0.250; and Site 5- 0.384.

1.4.3 Braddock Pool

The Braddock Pool is 12.6 miles long and starts at river mile 11.2 near Braddock, PA (FIGURE 36). Sites 6-11 were located within this pool. A total of 2,245 square meters were surveyed with a mean site search area of 374.2 m^2 and an average dive length of 31.2 meters. The average site depth was 14.5 feet. A total of 72 live mussels were found in this pool representing two separate species. A total of 71 pink heelsplitters (*P. alatus*) were found from sites 6-11. The pink heelsplitter totals for the sites were the following: Site 6- three mussels; Site 7- four mussels; Site 8- seven mussels; Site 9- 21 mussels; Site 10- 23 mussels; Site 11- 13 mussels. A single mapleleaf mussel was found at Site 9 and represented the only other species found besides pink heelsplitters in the Braddock Pool. The mussel density in the Braddock Pool from these six sites was found to be 0.032 mussels per m^2, the highest density found during this survey. Of the 72 dives made in the Braddock Pool, 54 of them reported no zebra mussel presence. Eight dives reported seeing one individual zebra mussel and ten dives reported two or more individual occurrences. Zebra mussel means per site, based on the 1-5 ranking method, were as follows: Site 6-0.667, Site 7- 0.167, Site 8- 1.167, Site 9- 0.167, Site 10- 0.250, and Site 11-0.0.

1.4.4 Pool 3

Pool 3 is 17.7 miles long and begins at river mile 23.8 near Elizabeth, PA (FIGURE 37). Sites 12-15 were located within this pool. A total of 1,763 square meters was surveyed with an average site search area of 440.8 m^2 and an average dive length of 36.7 meters. The average site depth was 9.0 feet. A total of 13 mussels were found in this pool representing two separate species. 12 pink heelsplitters (*P. alatus*) were found from sites 12, 14, and 15. One fat mucket mussel (*L. siliquoidea*) was found at Site 14 representing the only other species found in this pool. No mussels were found at Site 13, a total of 399 square meters were surveyed. The mussel density in Pool 3 from these four sites was found to be 0.008 mussels per m^2. Of the 48 dives made in Pool 3, 37 dives reported no zebra mussel presence. Five dives reported seeing one individual and six dives reported seeing two or more individuals. Zebra mussel means per site, based on 1-5 ranking method, were as follows: Site 12-0.167, Site 13- 0.333, Site 14- 0.500, and Site 15- 0.417.

1.4.5 Pool 4

Pool 4 is 19.7 miles long and begins at river mile 41.5 near Charleroi, PA (FIGURE 38). Sites 16-22 are located within this pool. A total of 3,195 square meters was surveyed in Pool 4 with an average site search area of 456.4 m^2 and an average dive length of 38.0 meters. The average transect depth was 12.7 feet. A total of 23 mussels was found in Pool 4 representing three separate species. Eighteen of the mussels found were pink heelsplitters (*P. alatus*) and were found at sites 17-22. A total of four fat mucket mussels (*L. siliquoidea*) was found at sites 17, 18 and 21. One threeridge mussel (*A. plicata*) was found at Site 18 and represents the only threeridge mussel found in the study. Site 16 was the only site in Pool 4 to have no mussels found. The mussel density in Pool 4 from these seven sites was found to be 0.007 mussels per m^2. Of the 84 dives made, 59 reported no evidence of zebra mussels. Fifteen of the dives reported seeing two or more individual zebra mussels. Nine dives reported seeing one individual zebra mussel and one dive reported seeing clumps of zebra mussels. Site 19 represented the only sighting of zebra mussels clumping together in the study. Zebra mussel means per site, based on the 1-5 ranking method were as follows: Site 16-0.667, Site 17- 0.00, Site 18- 0.250, Site 19-0.917, Site 20- 1.167, Site 21-0.250, and Site 22-0.250.

1.4.6 Maxwell Pool

Maxwell Pool is 20.3 miles long and begins at river mile 61.2 approximately five miles south of Brownsville, PA (FIGURE 39). Sites 23-27 are located within this pool. A total of 2,442 square meters were surveyed in the Maxwell Pool with an average site search area of 488.4 m^2 and an average dive length of 40.7 meters. The average transect depth was 13.5 feet. A total of 19 mussels were found in the Maxwell Pool and only accounted for one species. Nineteen pink heelsplitter mussels (*P. alatus*) were found in the Maxwell Pool with the following numbers: Site 23 – seven mussels; Site 24 – nine mussels; Site 25 – one mussel; Site 26 – two mussels. No mussels were found in Site 27. The mussel density in the Maxwell Pool from these five sites was found to be 0.008 mussels per m^2. Of the 60 dives made in the Maxwell Pool, 54 of them reported no zebra mussel occurrences. Six occurrences of single zebra mussel individuals were found from Sites 23 and 24. No zebra mussel activities were found in Sites 25, 26, or 27. Zebra mussel means per site, based on the 1-5 ranking method, were as follows: Site 23-0.250, Site 24- 0.250, Site 25- 0.00, Site 26- 0.00, and Site 27- 0.000.

1.4.7 Grays Landing Pool

Grays Landing Pool is 8.2 miles long and begins at river mile 82.0 near the town of Grays Landing, PA (FIGURE40). Sites 28-31 were located within this pool. A total of 1,867 square meters were surveyed in Grays Landing Pool with an average site search area of 466.8 m^2 and a average dive length of 38.9 meters. The average transect depth was 10.6 feet. A total of two mussels were found in Grays Landing Pool representing two species. The two species found were the pink heelsplitter (*P. alatus*) at Site 29 and a fat mucket Mussel (*L. siliquoidea*) also found at Site 29. The mussel density in Grays Landing Pool from these four sites was found to be 0.001 mussels per m^2, the lowest found during this survey. No mussels were found at sites 28, 30, or 31. In 48 dives, Sites 29-31, within Grays Landing Pool there was no evidence of any zebra mussel colonization.

TABLE 1. Sampling site locations in the Monongahela River by pool.

Pool	Sampling Site	River Mile	UTME	UTMN
Emsworth	1	0.28	583797.8	4476839.4
	2	3.42	588460.8	4475311.0
	3	4.00	588670.3	4474506.7
	4	5.42	589665.7	4472527.2
	5	7.49	591864.5	4474190.8
Braddock	6	12.17	598166.6	4470814.0
	7	12.50	598473.8	4470389.1
	8	15.74	595576.6	4467849.9
	9	18.03	593624.6	4464732.0
	10	20.27	595958.3	4462330.1
	11	21.66	595842.2	4460273.4
Pool 3	12	26	591140.7	4455431.3
	13	29.99	588892.7	4452073.8
	14	31.57	591212.7	4451170.5
	15	40.37	593404.8	4446248.6
Pool 4	16	45.46	598171.7	4440463.1
	17	46.86	598901.9	4438296.8
	18	50.97	593710.1	4436594.3
	19	51.34	594152.2	4436253.3
	20	56.53	594164.4	4430839.6
	21	57.04	593214.6	4430741.9
	22	59.92	590480	4427795.2
Maxwell	23	62.43	587419.9	4429702.0
	24	63.6	585671.3	4429131.2
	25	75.38	591752.4	4416931.7
	26	75.97	592162.2	4416055.5
	27	78.64	592026.7	4412715.2
Grays Landing	28	85.48	591776.4	4404560.2
	29	86.12	591234.2	4403850.1
	30	87.61	591548.9	4401627.5
	31	87.88	591805.8	4401253.5

TABLE 2. Summary of sampling stations for mussel collection, species diversity, depth, and search areas in the Monongahela River, PA.

Pool	Sampling Station	Ave Depth (ft)	Total Area (m^2)	Mean Area/transect (m^2)	Mussels Total	Species Diversity	Mussels (Dead/ Halfs)*	Zebra Score Ave
Emsworth	1	14.25	247	20.58	1	1	0	0.333
	2	13.75	286	23.83	4	2	2	0.167
	3	16.4	303	25.25	7	1	2	0.833
	4	8.33	364	30.33	5	3	0	0.250
	5	14.61	265	20.38	2	2	2	0.384
Braddock	6	18.75	305	25.42	3	1	0	0.667
	7	19.58	350	29.17	4	1	6	0.167
	8	14.23	390	30.58	7	1	8	1.167
	9	12.33	355	29.58	22	1	11	0.167
	10	10.58	366	30.50	23	1	7	0.250
	11	11.58	479	39.92	13	1	10	0.000
Pool 3	12	7.91	524	43.67	1	1	2	0.167
	13	8.42	399	33.25	0	0	14	0.333
	14	9.33	458	38.17	9	2	15	0.500
	15	10.5	382	31.83	4	1	13	0.417
Pool 4	16	11.91	503	41.92	0	0	5	0.667
	17	12.75	604	50.33	4	2	1	0.000
	18	13.66	350	29.17	5	3	9	0.250
	19	16.25	398	33.17	2	1	7	0.917
	20	9.16	394	32.83	5	1	14	1.167
	21	10.42	443	36.92	5	2	16	0.250
	22	14.67	503	41.92	1	1	8	0.250
Maxwell	23	17.5	507	42.25	7	1	1	0.250
	24	15.25	556	46.33	9	1	1	0.250
	25	12.33	432	36.00	1	1	0	0.000
	26	11.66	533	44.42	2	1	0	0.000
	27	11.0	414	34.50	0	0	1	0.000
Grays Landing	28	7.58	532	44.33	0	0	0	0.000
	29	10.91	419	34.92	2	2	0	0.000
	30	11.5	493	41.08	0	0	0	0.000
	31	12.42	423	35.23	0	0	0	0.000
Total/Mean		12.57	12977		148	7	155	0.316

*Column values are counted in half-valve dead shells collected during dive transects

TABLE 3. Summary of transect length, search area, total area, mussels collected and zebra mussel scores collected by river pool within the Monongahela River, PA in 2008.

Pool Name	Number of sites	Transect Mean Length (m)	Site Search Area Mean (m^2)	Total Area (m^2)	Mussels Per Site Mean	Mussel Per (m^2)	Total Live Mussels	Mean zebra mussel score
Emsworth	5	24.07	293.0	1465	3.8	0.013	19	0.393
Braddock	6	30.86	374.2	2245	12	0.032	72	0.403
Pool 3	4	36.73	440.8	1763	3.5	0.008	14	0.354
Pool 4	7	38.04	456.4	3195	3.1	0.007	22	0.500
Maxwell	5	40.07	488.4	2442	3.8	0.008	19	0.100
Grays Landing	4	38.89	466.8	1867	0.5	0.001	2	0.000

TABLE 4. Summary of mussel species collected by river pool and site number within the Monongahela River, PA in 2008.

		Location by Pool						
Species	Total	Emsworth	Braddock	Pool 3	Pool 4	Maxwell	Grays Landing	Site Number
Potamalis alatus	135	14	71	12	18	19	1	2-12,14,15,17-26,29
Lasmigona costata	1	1	0	0	0	0	0	2
Leptodea fragilis	1	1	0	0	0	0	0	1
Pyganodon grandis	1	1	0	0	0	0	0	4
Quadrula quadrula	2	1	1	0	0	0	0	4,9
Lampsilis siliquoidia	7	1	0	1	4	0	1	5,14,17,18,21,29
Amblema plicata	1	0	0	0	1	0	0	18
Species Total:	7	6	2	2	3	1	2	
Totals:	148	19	72	13	23	19	2	

TABLE 5. Results of the Monongahela River Mussel and Substrate survey of 2008 by River Site.

Site	River Mile	Mussel Abundance	Species Diversity	Average Depth (ft)	Search Area (m²)	Mussel Per (m²)	Adjusted % Fines	Adjusted % Sand	Adjusted % Gravel	Adjusted % Cobble	Adjusted % Boulder	Adjusted % Bedrock
1	0.28	1	1	14.3	247	0.004	71	10	10.6	0.7	7.7	0
2	3.42	4	2	13.8	286	0.014	64.9	11.8	11.5	8.5	3.3	0
3	4.00	7	1	16.4	303	0.023	89.2	4	3.4	1.7	1.7	0
4	5.42	5	3	8.3	364	0.014	90.8	2.1	4.3	2.9	0	0
5	7.49	2	2	14.6	265	0.008	31.7	6.3	10.4	16.3	5.9	29.5
6	12.17	3	1	18.8	305	0.010	29.4	6.8	16	29.9	17.9	0
7	12.50	4	1	19.6	350	0.011	41.8	3.1	14.4	23.2	16.6	0.9
8	15.74	7	1	14.2	390	0.018	93.1	2.3	1.1	2.9	0.6	0
9	18.03	22	1	12.3	355	0.062	89	2.9	3.8	3.3	1.1	0
10	20.27	23	1	10.6	366	0.063	99.2	0	0	0.9	0	0
11	21.66	13	1	11.6	479	0.027	68.8	17.9	5.5	4.4	1.4	2
12	26.00	1	1	7.9	524	0.002	60.5	5.9	33.2	0.5	0	0
13	29.99	0	0	8.4	399	0.000	98	0	1.6	0	0.5	0
14	31.57	9	2	9.3	458	0.020	87.8	2.5	3.6	6.2	0	0
15	40.37	4	1	10.5	382	0.010	60.3	6	14.1	14.9	3.6	1.2
16	45.46	0	0	11.9	503	0.000	96.1	0.8	0	1.2	1.8	0
17	46.86	4	2	12.8	604	0.007	100	0	0	0	0	0
18	50.97	5	3	13.7	350	0.014	88.1	6.8	2.5	2.3	0.3	0
19	51.34	2	1	16.3	398	0.005	84.7	0.4	0.4	2.1	11.5	0.9
20	56.53	5	1	9.2	394	0.013	78.3	0	5.1	7.3	9.3	0
21	57.04	5	2	10.4	443	0.011	88.2	8.2	1.1	2.5	0	0
22	59.92	1	1	14.7	503	0.002	51.9	3.7	13.3	9.5	12.7	9.1
23	62.43	7	1	17.5	507	0.014	85.7	0	3.4	5.7	5.2	0
24	63.60	9	1	15.3	556	0.016	95.3	0	0.6	1.6	2.6	0
25	75.38	1	1	12.3	432	0.002	94.9	0	2.3	0.7	2.1	0
26	75.97	2	1	11.7	533	0.004	62.7	0.7	6.2	18.7	11.7	0
27	78.64	0	0	11	414	0.000	71.1	0	10.2	10.1	8.6	0
28	85.48	0	0	7.6	532	0.000	100	0	0	0	0	0
29	86.12	2	2	10.9	419	0.005	63	2.6	4.1	15.9	14.5	0
30	87.61	0	0	11.5	493	0.000	99.6	0.4	0	0	0	0
31	87.88	0	0	12.4	423	0.000	93.1	1.2	2.5	2.2	1	0

*Adjusted results are the combination of 12 transects per site combined.

FIGURE 6. Pie chart of mussel population abundance break down within PA Monongahela River.

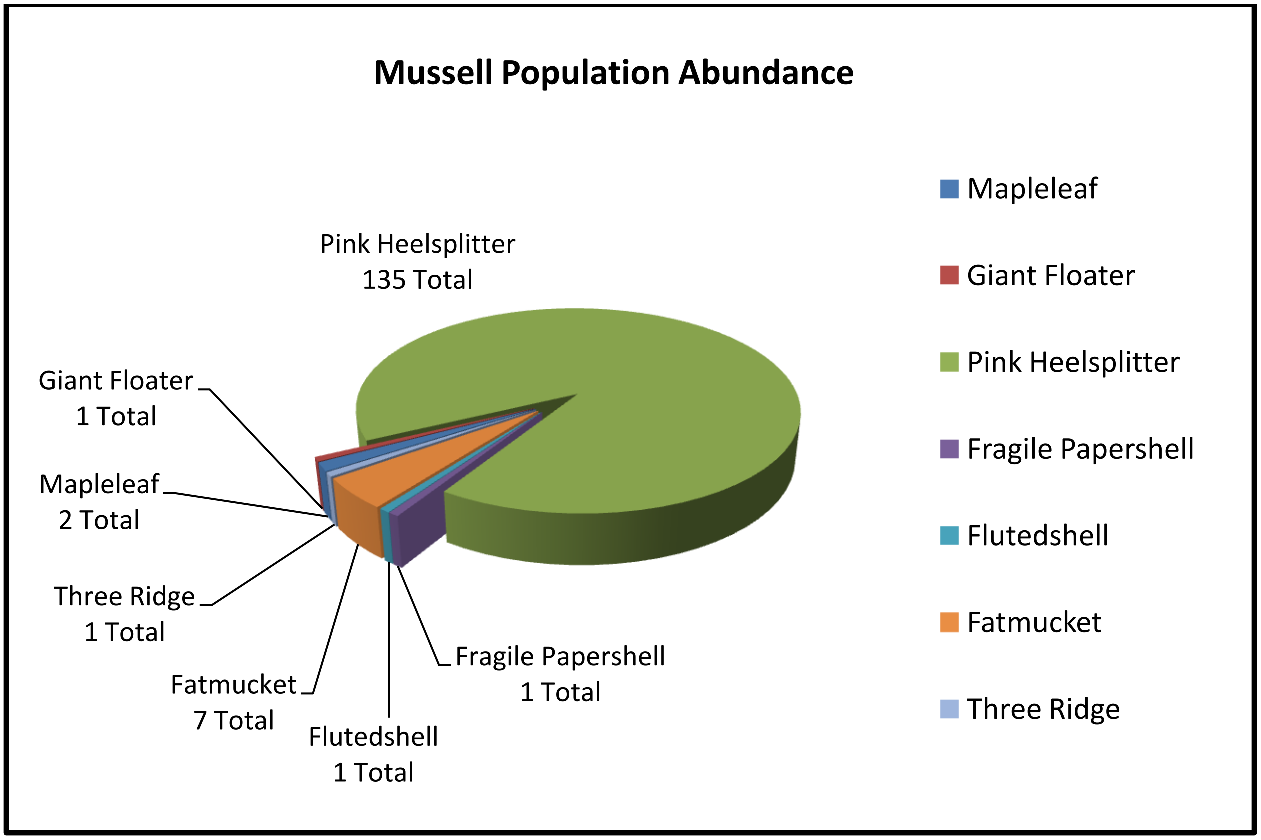


FIGURE 7. Cumulative number of mussels found compared to cumulative number of species in the Monongahela River, PA sampling sites 1-31.

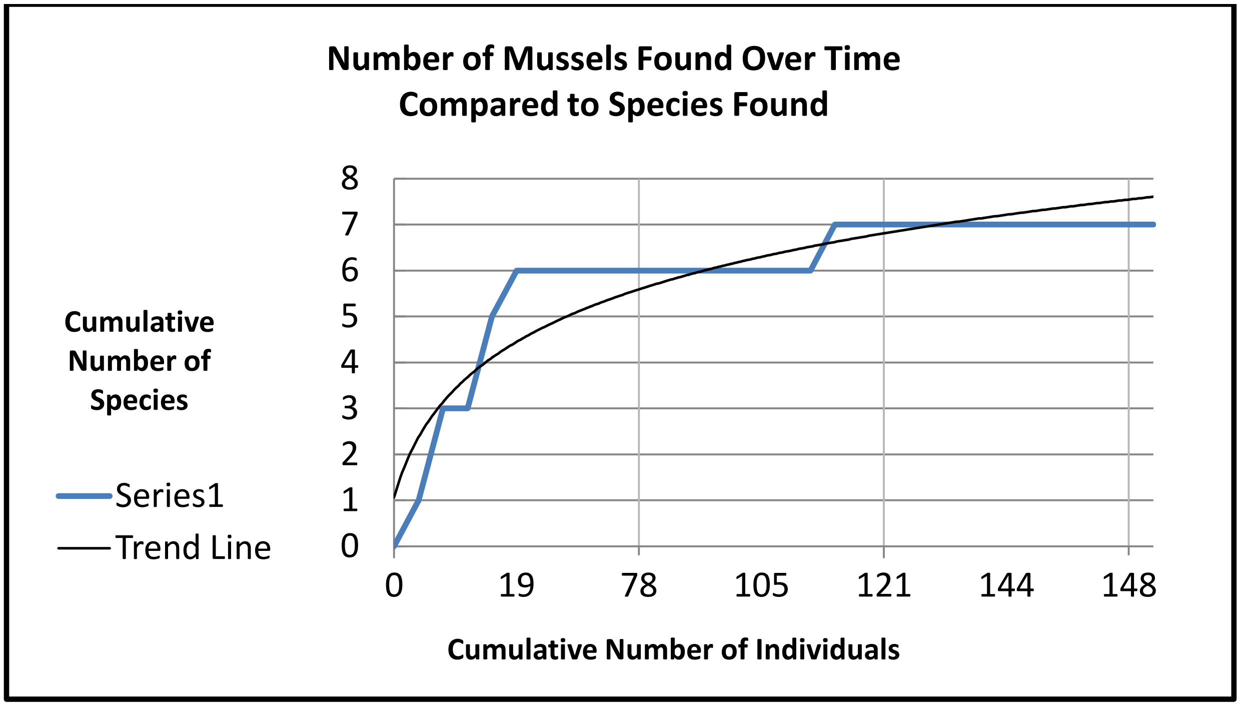


FIGURE 8. Cumulative number of mussel species found over time in relation to sampling hours searched on the Monongahela River, PA.

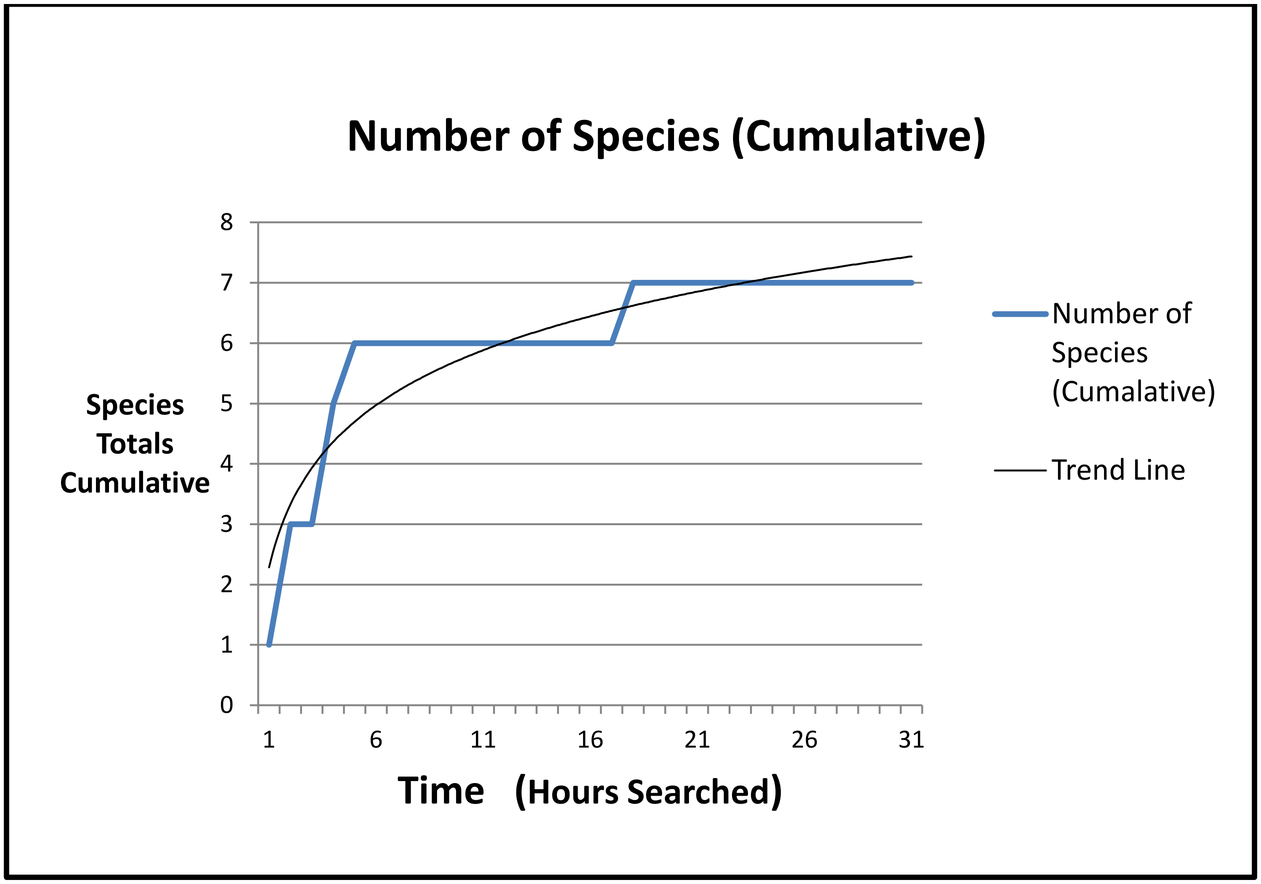


FIGURE 9. Scatter plot of the average fines and cobbles by site plotted against the total area searched by site within the Monongahela River, PA.

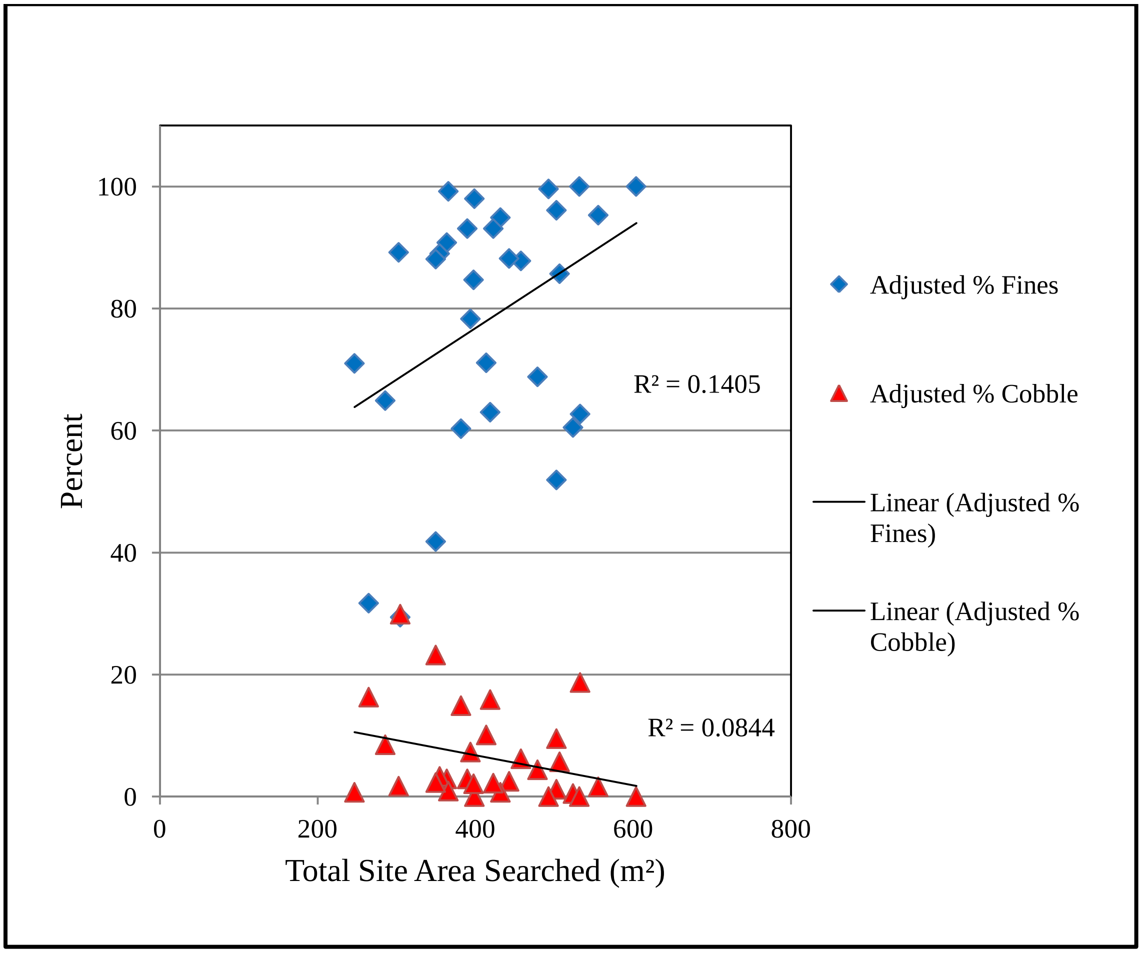


FIGURE 10. Scatter plot of dive depth versus mussel abundance collected by survey site within the Monongahela River, PA.

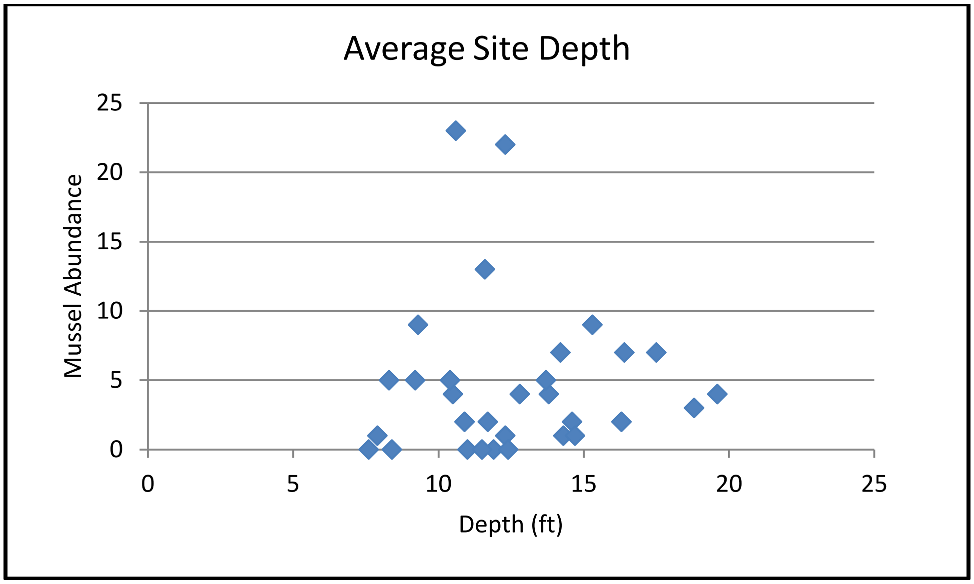
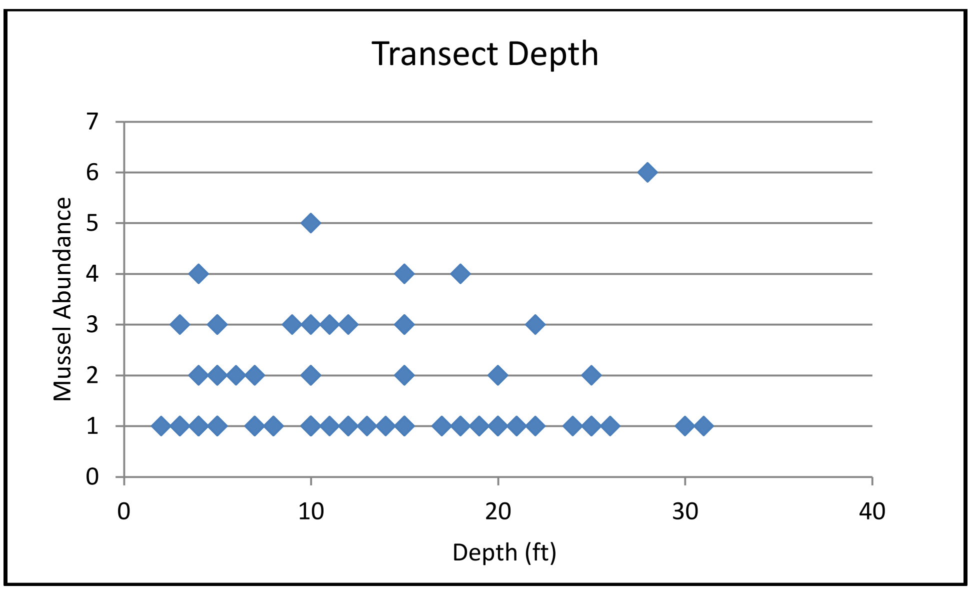


FIGURE 11. Scatter plot of dive depth versus mussel abundance collected by transect excluding transects where no mussels were found within the Monongahela River, PA.



1.5 DISCUSSION

Historical accounts of the aquatic diversity in the Monongahela River have shown severely devastated environments. There has been extremely limited work done with freshwater mussels in the Monongahela River to date. The first published accounts of freshwater mussels in the Monongahela was the "Monograph of Naiades of Pennsylvania" published in 1919 (Ortmann 1919). Ortmann described the Monongahela River as "utterly polluted, chiefly by mine water," from the vast coal mining operations in the area (Ortmann 1919). Even with the dozens of tributaries entering the Monongahela River, Ortmann could only name Dunkard Creek, Ten Mile Creek, and South Fork of Ten Mile Creek as in "good condition." Later years would show devastating mine drainage and oil spills to these creeks, depriving the Monongahela of any decent tributaries (Dennis 1971). Shapiro in 1967 reported that the river's water quality was severely limited and "did not support any significant fisheries" (Hoskin et al., n.d.). Fisheries in the late nineteenth and twentieth centuries were limited to upper headwater habitats where water quality remained suitable. The water quality in the mid-twentieth century became so grossly devastated that certain pools became completely devoid of fish life (Hoskin et al. n.d.).

With the enactment of water quality standards in the 1970s fish began to reappear in the river. Original recolonization of the river began from headwater species and slowly grew as distant downstream species began to arrive. The lock and dam systems set in place hinder many of the species re-entering the river and delayed river rehabilitation (Holland 1984).

This trend can be seen across the few mussel surveys which took place over the twentieth century on the Monongahela. Ortmann's first account of the river, though still utterly polluted at that point, noted 28 species of mussels in the river (TABLE 6 & 7). Of these 28 species referenced, three species referenced were only known from archaeological shells found in middens at Point Marion, PA in 1909 and included *Cyprogenia stegaria*, *Epioblasma torulosa rangiana*, and *Lampsilis spp*. None of these species have been found alive within the Monongahela River nor its tributaries. The true account of the original mussel population before human alteration may never be known but Ortmann's original account is the greatest diversity noted in the river to date.

In 1971, Sally Dennis surveyed three tributaries of the Monongahela River basin, Whiteley Creek (Maxwell Pool), Ten Mile Creek (Maxwell Pool) and South Fork Ten Mile Creek (Maxwell Pool) for mussels and found only 5 species (TABLE 7). Her reporting from 45 sampling sites on 10 tributaries of the Monongahela found that 37 sampling sites were devoid of mussels. Dennis's survey in the Monongahela drainage focused upon Ortmann's three "good condition" tributaries, Whiteley, Ten Mile, and South Fork of Ten Mile Creeks (Dennis 1971). However, it must be noted that Dennis's search focused primarily on tributaries and can't actually account for the actual mussel populations that may have occurred in the Monongahela River at that time. Her survey did note that of the species found, none of them had any significant population numbers.

In 1982, Michael Zeto of the West Virginia Department of Natural Resources investigated the upper headwaters of the Monongahela River in West Virginia within four tributaries. These tributaries included the West Fork River, the mouth of Hackers Creek, Buffalo Creek, and Dunkard Creek. Though headwater habitats and species can vary greatly, it is in decent regard to account for the possibility of other species in the drainage system. Zeto found 15 species of mussels to be present in the headwaters of the Monongahela River (TABLE 7). He noted finding one species which was not noted in Ortmann's 1919 survey. This species was the salamander mussel (*Simpsonaias ambigua*), a mussel species that may have existed in the Monongahela proper prior to human alteration and pollution (Zeto 1982).

In 1987, W.A. Tanner reported that no live or dead freshwater mussels existed in the Monongahela River. Tanner surveyed the lower 41.5 miles of the Monongahela River and found no existence or evidence of mussel populations which serves as a note on the mussel fauna within the river at that time (TABLE 7) (Tolin 1987) (Bogan 1993).

In 1993, Arthur Bogan surveyed six sites on the Monongahela River proper and also found no evidence of mussels present. According to Bogan, historical data indicates, primarily from Ortmann and archaeological literature, that 29 species have been noted as existing in the Monongahela River. Four of these twenty-nine species were accounted for through archaeological evidence from shell middens which included the species *Cyprogenia stegaria*, *Epioblasma torulosa rangiana*, *Hemistena lata*, and *Lampsilis ovata*. Bogan himself found no evidence of mussel populations in the six river site surveys on the Monongahela River that he conducted but did note numerous invasive *Corbicula fluminea* shells on the river banks as well as abundant trash (TABLE 6). Bogan's Monongahela River survey sites included three within Fayette County, PA within Pool 4 (at river mile 56.45), Maxwell Pool (at river mile 75.7), and Grays Landing Pool (at river mile 90.63). Two site locations located in Washington County PA within Pool 3 at river mile 32.34 and Pool 4 at river mile 43.6. The remaining site was located in Allegheny County, PA within the Braddock Pool at river mile 15.54. Bogan noted that possibilities of tolerant species inhabiting the river do exist for species such as *Lasmigona costata*, *Pyganodon grandis*, *Strophitus undulatus*, and *Utterbackia imbecillis* likely through re-invasion.

Bogan's 1993 survey represents the most comprehensive survey of the Monongahela River Basin since Ortmann's original. Including the six Monongahela River proper survey sites, Bogan surveyed 133 locations across the basin which included the 8 major tributaries of historic and modern representation of mussel fauna. In total, Bogan found 17 species to be represented in the Monongahela River basin (TABLE 7). Of particular note regarding his findings were *Simpsonaias ambigua*, *Utterbackia imbecillis*, and *Lasmigona compressa* which had not been recorded by Ortmann to be present in the basin. Bogan also accounted for three species introduced into the basin from Atlantic coast drainages which included *Elliptio complanata*, *Lampsilis radiata*, and *Pyganodon cataracta* (TABLE 7).

The 2008 Marshall University survey found seven species: *A. plicata*, *L. siliquoidea*, *L. costata*, *L. fragilis*, *P. alatus*, *P. grandis*, and *Q. quadrula*. Two of these species were unaccounted for by Ortmann's original survey, *A. plicata*, and *Q. quadrula*, within the Monongahela River proper. *Amblema plicata* was found in the tributaries of the Monongahela by Ortmann, Bogan, and Zeto but not in the river itself. This species may be a headwater re-introduction and not an original Monongahela River proper species. *Quadrula quadrula* has not been collected within the Monongahela River or tributaries before 2008 to the authors knowledge (TABLE 6). This species is likely a reintroduction to the basin through upstream fish host migration from the Ohio River where it is common species. *Potamilus alatus* was noted as an original species within the Monongahela River by Ortmann but was not noted as present within tributaries from Ortmann, Zeto and Bogan. 91.2% of the population abundance within the 2008 survey was composed of *P. alatus* indicating a successful reintroduction into the Monongahela River main stem (TABLE 6). The following is a species account for the Monongahela River mussel population found by the 2008 survey.

1.5.1 Species Ecology

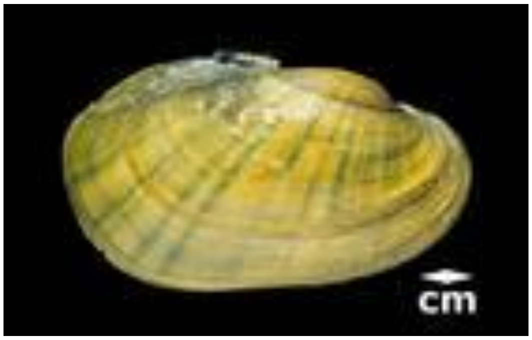
Listed below are the species accounts of mussels collected during the 2008 Monongahela River survey. Mussel glochidia to fish host relationships are defined as listed by the two-letter code devised by Dr. Michael Hoggarth of Otterbien University as follows: NI- natural infestation of parasite found on wild fish but no metamorphosis observed; NT- natural infestation with metamorphosis observed; LI- laboratory infestation with no metamorphosis observed; LT-laboratory infestation with metamorphosis observed; NS- not stated in original source (Cummings et al., 2003).

1.5.1.1 *Potamilus alatus*- Pink Heelsplitter Mussel

(Little, n.d.)

The most prevalent mussel found in the 2008 survey with 135 individuals. This mussel was the only species found in each Monongahela River Pool within Pennsylvania during the 2008 survey (TABLE 1 & 2). *P. alatus* was an original species found by Ortmann in 1919 for the Monongahela River and tributaries and was noted as absent by Zeto (1982) and Bogan (1993). *P. alatus* is a relatively fast moving species which prefers mud, silt or fines as habitat. The mussel is common in medium-sized streams to large rivers (Cicerello et al., 2003). The primary host fish species for *P. alatus* is the freshwater drum *Aplodinotus grunniens* (NI, NS) (Cummings et al., 2003).

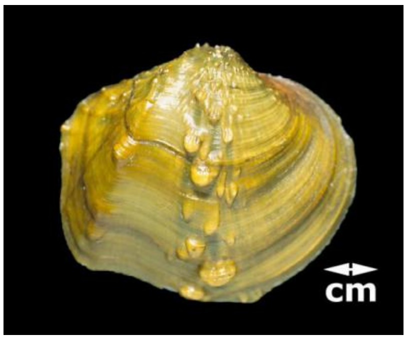
1.5.1.2 *Lampsilis siliquoidea*- Fat Mucket Mussel



(Warren, n.d.)

This was the second most prevalent mussel found in the 2008 survey with a total 7 individuals found from the Emsworth Pool, Pool 3, Pool 4, and Grays Landing Pool (TABLE 1 & 2). This species was originally found by Ortman (1919) in the Monongahela River. Dennis (1971) and Zeto (1982) found the fat mucket to be one of the more common species in the tributaries of the Monongahela. Not commonly found in large rivers, such as the Monongahela, the fat mucket prefers small to medium sized rivers in mud, sand, or gravel habitats. This species prefers calm water such as found in pools or below riffles (Cicerello et al., 2003). This species has a wide variety of fish host species: bluegill *Lepomis macrochirus* (LT, LI, NI), green sunfish *Lepomis cyanellus* (LT), longear sunfish *Lepomis megalotis* (LT), smallmouth bass *Micropteris dolomieu* (LT), largemouth bass *Micropteris salmoides* (LT,NI), sand shiner *Notropis ludibundus* (LT), bluntnose minnow *Pimephales notatus* (LT), florida gar *Lepisosteus platyrhincus* (LT), rock bass *Ambloplites rupestris* (LI), white sucker *Catostomus commersoni* (NS), pumpkinseed *Lepomis gibbosus* (NI), warmouth *Lepomis gulosus* (NI), striped shiner *Luxilus chrysocephalus* (LT), common shiner *Luxilus cornutus* (NS), white bass *Morone chrysops* (LT), tadpole madtom *Noturus gyrinus* (NS), yellow perch *Perca flavescens* (LP, NS, NI, LT), white crappie *Poxomis annularis* (NI), black crappie *Pomoxis nigromaculatus* (LT, NI), sauger *Sander Canadensis* (LT), walleye *Sander vitreus* (NS, LT, NI). (Dennis 1971) (Cummings et al., 2003).

1.5.1.3 *Quadrula quadrula*- Mapleleaf Mussel



(Warren, n.d.)

This was the third most common species found in the 2008 survey with a total of 2 individuals found from the Emsworth and Braddock Pools. To the authors, knowledge this is the first account of this species within the Monongahela River. This mussel was not found by Ortmann, Dennis, Veto, or Bogan in the Monongahela River or its tributaries. This mussel is a common occurrence far downstream in the Ohio River and is likely to have migrated northward with fish host movement. The Mapleleaf prefers small to large sized rivers in mud, sand, or gravel (Cicerello et al., 2003). The primary host fish for the mapleleaf is the channel catfish *Ictaluris punctatus* (LT) and the flathead catfish *Pylodicits olivaris* (NI). (Cummings et al., 2003).

1.5.1.4 *Amblema plicata*- Threeridge Mussel

(Warren, n.d.)

One threeridge mussel was found in Pool 4. To the authors knowledge this is the first account of this species within the Monongahela River main stem. It was accounted for by Zeto (1982) and Bogan (1993) in the headwaters of the Monongahela River tributaries. It is possible that this mussel may have colonized the lower Monongahela River after suitable habitat and water quality returned. *A. plicata* prefers small streams to large rivers in mud, sand, or gravel with slow to still moving water such as found in reservoirs or pools (Cicerello et al., 2003). The primary fish host species for this mussel are rock bass *Ambloplites rupestris* (LT), freshwater drum *Aplodinutus grunniens* (NI), spotfin shiner *Cyprinella spiloptera* (NI), steelcolor shiner *Cyprinella whipplei* (NI), streamline chub *Erimystax dissimilis* (NI), northern pike *Esox lucius* (NI), mooneye *Hiodon tergisus* (NI), northern hogsucker *Hypentelium nigricans* (NI), channel catfish *Ictalurus punctatus* (NI), shortnose gar *Lepisosteus platostomus* (LT, LI), green sunfish *Lepomis cyanellus* (LT), pumpkinseed *Lepomis gibbosus* (LT, NI), warmouth *Lepomis gulosus* (NI), bluegill *Lepomis macrochirus* (LT, NI), largemouth bass *Micopterus salmoides* (LT, NI), white bass *Morone chrysops* (NI), black redhorse *Moxostoma duquesnei* (NI), golden redhorse *Moxostoma erythrurum* (NI), emerald shiner *Notropis atherinoides* (NI), yellow perch *Perca flavescens* (LT, NI), logperch *Percina caprodes* (NI), white crappie *Pomoxis annularis* (NI, LT), black crappie *Pomoxis nigromaculatus* (NI, LT), flathead catfish *Pylodictis olivaris* (NS), sauger *Sander Canadensis* (NI) (Cummings et al., 2003).

1.5.1.5 *Pyganodon grandis*- Giant Floater

(Warren, n.d.)

One Giant Floater mussel was found during the 2008 survey in the Lower Monongahela Emsworth Pool near Pittsburgh, PA. This mussel in an original inhabitant of the Monongahela River and was found by Ortmann, Dennis, Zeto and Bogan (TABLE 6). *P. grandis* prefers small to large rivers with clay, silt, or mud. This mussel prefers calm waters such as found in lakes, wetlands, ponds, and reservoirs. The mussel shell is thin and fragile leaving the mussel vulnerable to excessive current or abrasive substrate. The primary host fish species for this mussel are the skipjack herring *Alosa chrysochloris* (NI), rock bass *Ambloplites rupestris* (NI, LT), yellow bullhead *Ameriurus natalis* (NI), freshwater drum *Aplodinotus grunniens* (NI), central stoneroller *Campostoma anomalum* (NI, LT), river carpsucker *Carpiodes carpio* (NS), goldfish *Carrasius auratus* (LT), white sucker *Catostomus commersoni* (NS), Rio Grande cichlid *Cichlasoma cyanoguttatum* (LT), brook stickleback *Culaea inconstans* (NS, LT), common carp *Cyprinus carpio* (NS, NI), gizzard shad *Dorosoma cepedianum* (NI), rainbow darter *Etheostoma caeruleum* (NI, LT), Iowa darter *Etheostoma exile* (NS, NI, LT), johnny darter *Etheostoma* *nigrum* (NI, NS, LT), golden topminnow *Fundulus chrysotus* (LT), banded killifish *Fundulus diaphanous* (LT), brook silverside *Labidesthes sicculus* (NI, LT), longnose gar *Lepisosteus os*seus (LT), green sunfish *Lepomis cyanellus* (NI, LT), pumpkinseed *Lepomis gibbosus* (LT), orangespotted sunfish *Lepomis humulis* (LT), bluegill *Lepomis macrochirus* (NI, LT, NS), longear sunfish *Lepomis megalotis* (LT), striped shiner *Luxilus chrysocephalus* (NI, LT), common shiner *Luxilus cornutus* (NI, LT, NS), redfin shiner *Lythrurus umbratilis* (LT), pearl dace *Margariscus margarita* (NI), largemouth bass *Micropterus salmoides* (NI, LT, NS), white bass *Morone chrysops* (NI), round goby *Neogobius melanostomous* (LT), golden shiner *Notemigonus crysoleucas* (LT), blackchin shiner *Notropis heterodon* (NI, LT), blacknose shiner *Notropis heterolepis* (NI, LT), yellow perch *Perca flavescens* (NI, LT), bluntnose minnow *Pimephales notatus* (NI, LT), guppy *Poecilia reticulate* (LT), white crappie *Pomoxis annularis* (NI, NS, LT), black crappie *Poxomis nigromaculatus* (NI, LT), blacknose dace *Rhinichthys atratulus* (LT), roach *Rutilus rutilus* (NS), and creek chub *Semotilus atromaculatus* (LT). (Cicerello et al., 2003) (Cummings et al., 2003).

1.5.1.6 *Leptodea fragilis*- Fragile Papershell Mussel

(Little, n.d.)

One Fragile Papershell Mussel was found in the Monongahela River within the Emsworth Pool. This mussel was not found by Bogan, Dennis, or Zeto in previous Monongahela River surveys but was noted as originally present by Ortmann (1919) (TABLE 6). This species ia a commonly found mussel in the Ohio River downstream. *L. fragilis* prefers small streams to large rivers with calm areas of mud, sand, or gravel. The thin shell is prone to cracking and is not conducive to high current or rock environments. *L. fragilis* is often found in reservoirs or pools where unconsolidated mud or fines provide stable habitat (Cicerello et al., 2003). The primary fish host species for *L. fragilis* is the freshwater drum *Aplodinotus grunniens* (NI). (Cummings et al., 2003)

1.5.1.7 *Lasmigona costata*- Flutedshell Mussel

(Little, n.d.)

One Flutedshell Mussel was found in the Monongahela River within the Emsworth Pool near Pittsburgh, PA. *L. Costata* is an original species for the Monongahela River and was found by Ortmann, Dennis, Veto, and Bogan in previous surveys (TABLE 6). The mussel is generally distributed across the Mississippi drainage and prefers mud, sand, gravel, or rocky interstitial habitats. The mussel has a wide range of habitats from small to large rivers and fast or slow moving current (Cicerello et al., 2003). The primary host fish species for this mussel is the banded darter *Etheostoma zonale* (LT), northern hogsucker *Hypentelium nigricans* (LT), pumpkinseed *Lepomis gibbosus* (LT), largemouth Bass *Micropteris salmoides* (LT), longnose dace *Rhinichthys cataractae* (LT), rock bass *Ambloplites rupestris* (LT), brown bullhead *Ameiurus nebulosus* (LT), bowfin *Amia calva* (LT), central stoneroller *Campostoma anomalum* (LT), goldfish *Carrasius auratus* (LT), banded sculpin *Cottus carolinae* (LT), common carp *Cyprinus carpio* (LT), gizzard shad *Dorosoma cepedianem* (NI), northern pike *Esox lucius* (LT), rainbow darter *Etheostoma caeruleum* (LT), fantail darter *Etheostoma flabellare* (LT), striped darter *Etheostoma virgatum* (LT), northern studfish *Fundulus catenatus* (LT), green sunfish *Lepomis cyanellus* (LT), bluegill *Lepomis macrochirus* (LT), longear sunfish *Lepomis megalotis* (LT), river redhorse *Moxostoma carinatum* (NI), yellow perch *Perca flavescens* (LT), walleye *Sander vitreus* (LT), and creek chub *Semotilus atromaculatus* (LT) (Cummings et al., 2003).

1.5.2 Sampling Design Discussion

Numerous difficulties are presented to malacologists when attempting to survey large rivers for mussels. Large river sampling often must include either scuba equipment or surface air hookah systems. This limits the surveyor's ability to effectively sample the river as compared to smaller rivers and streams where snorkeling and waist deep water are common. Finding effective sampling methods to adequately sample a river's mussel population is a common constraint to researchers. Time and budget often limit researchers from conducting quantitative sampling such as quadrants or excavation for species densities in large rivers, while species diversity and assemblages sampled using qualitative methods such as transects may be limited in providing diversity and accurate density values (Vaughn et al., n.d.). Other difficulties in large river sampling include the inability to decipher suitable habitats and locations of particular "mussel beds." Often quantitative or qualitative surveys in small streams or rivers are congregated around riffles or runs where mussels congregate for added nutrients in the water. In large rivers such as the Ohio, Mississippi, or Monongahela Rivers, no such riffles or runs exist; they are merely extensive reservoirs of slowly moving water between lock and dams. This leaves randomized sampling completely blind in attempts to locate any mussel congregations.

Numerous studies have researched the efficacy of timed searches compared to other sampling techniques. A particular common method of large river sampling is the 100-meter transect method. This method is often utilized by researchers, such as the W.V. Department of Natural Resources, and the U.S. Fish and Wildlife Service. This method randomizes the transect's originating location but maintains a perpendicular direction to water flow. The transect is conducted in ten meter increments for a total length of 100 meters across the river. This effectively samples the river's separate shore, slope, and channel habitats but does not include any leeway in habitats upstream or downstream. This method has been met with some concerns because an ill-placed transect origin may effectively miss numerous species in the river which may be congregated along bank or slope habitats. Timed searches have been shown to be more likely to account for more of the mussel species at a site in a river when compared to qualitative (quadrat) techniques (Vaughn et al., n.d.), although timed searches are biased towards surface-dwelling species, larger species, and those with distinctive shell sculptures. Smaller species and those which may bury deeply tend to be missed by timed searches (Vaughn et al., n.d.). Primary differences between quantitative (timed) sampling and qualitative (quadrat) sampling are mostly seen in species richness and composition. Little differences can be found in species diversity between the two methods (Hornbach and Deneka 1996). Though quadrat searches provide precise density estimates, timed searches also provide reliable relative abundances when focusing on large surface species (Vaughn et al., n.d.).

Vaughn elaborates further that if survey objectives are to locate mussel beds or rare species rather than qualitative project goals, timed searches are very applicable. If objectives are to determine abundance, density, or complete demographics then quantitative quadrants with sub-surface excavation are recommended. In large river mussel surveying, where air and time is limited by SCUBA, adequate quadrant sampling is nearly impossible (Vaughn et al, n.d.).

Our study focused upon determining what species were present in the Monongahela River and not density. Hornbach and Deneka (1996) and Vaughn et al., (n.d.) suggest that relative abundances from these accounts are reliable but also note that in particular *A. plicata* was often over counted likely due to *A. plicata'*s irregular shape and tendency to protrude above substrate surfaces (Vaughn et al., n.d.); (Hornbach and Deneka 1996). Hand collecting via

SCUBA is ultimately effective but fails to adequately sample juvenile mussels as well (Hornbach and Deneka 1996).

The number of individuals found in the Monongahela River was excessively low. This may be due to the river's long history of pollution or habitat alterations that have occurred over the past century. The ability to reasonably assess these effects and the complete mussel assemblage in the Monongahela is difficult. Miller and Payne (1993) for instance, indicated that approximately 700 individuals in a study are needed to significantly characterize a mussel assemblage. Hornbach and Deneka (1996) found at certain sites 700 individuals accounted for the majority but not necessarily the entirety of the assemblage. Though, this number of individuals is entirely sample location dependent as other sites needed approximately 200 to adequately approximate assemblage (Hornbach and Deneka 1996). Hornbach and Deneka (1996) also mentioned that *L. fragilis*, and *L. siliquoidea* were prone to be underestimated by timed searches.

Quantative methods of mussel sampling such as tactile and visual searches have been shown to give taxa richness values greater than or equal to those conducted using qualitative quadrant excavation searches primarily based on the increased mussels obtained (Hornbach and Deneka 1996). Obermeyer (1998) noted that timed searches versus quadrant searches did not significantly alter relative abundances or species diversity but noted that quadrant sampling increased species richness with more species (Obermeyer 1998). Vaughn has stated that more species are collected using timed searches in less man hours than quadrant, as the increased number of individuals collected during timed searches increases diversity at a more efficient rate (Vaughn et al., n.d.).

The primary goal of our survey was to document the diversity and richness in the Monongahela River over a vast area and the timed searches provided a degree of efficiency needed to sample across 91 river miles. The river size in combination with water depth, commercial barge traffic and a sparse mussel presence made quadrat or quantitative sampling nearly impossible. A total of 12,977 square meters of surface area were tactilely searched for mussel populations. A primary goal of this tactile search method was time efficiency due to both the large number of sites and area as well as the length of time air would last in a SCUBA tank. The timed searches inherently reduced the total search areas at each site by the ability of the diver to adequately search the substrate surface. In FIGURE 9, the mean percent of fines and cobble recorded by each transect were averaged to result in adjusted fines and cobble per site and graphed against total search area per site. This figure illustrates that as the percent of fines increased the divers search area was able to be increased. The opposite was seen as the diver encountered cobbled substrate areas. The difficulty in searching rocky substrate conditions, with its many crevices, limited divers search areas. This trend, common in timed SCUBA mussel sampling, has the inherent ability to trend mussel compositions to species preferring silt or muddy conditions which tend to be easier to search.

A relatively independent method of determining sampling efficacy is to relate the number of individual mussels collected in comparison to the number of species collected (Kovalak et al., 1996). This method is used to relatively determine the efficiency of sampling and to account for the number of species possible. In FIGURE 7, the cumulative number of mussels found during the 2008 survey is compared to the cumulative number of species found over time. It can be seen that the horizontal asymptote of the curves trend line is peaking near 8 mussel species (FIGURE 7).

A comparison of the efficacy of time spent searching for mussel species in the Monongahela can be compared against Hornbach's 1996 study. Hornbach surveyed 4 separate sites and compared quadrant sampling to timed searches for total assemblage efficiency. Of the 4 searches, two sites returned equal numbers of species (19 and 16 species respectively), while the other two timed searched surveys returned 25 of 27 (92.5%) and 22 of 28 (78.5%) species. The quantities of mussel species were of expected differences as stated earlier by Vaughn et al. (n.d.) and Miller and Payne (1993). Comparing Hornbach's search intervals for sufficient mussel sampling to the 2008 search intervals indicates sufficient sampling time did take place within the study. Hornbach's timed search intervals for sufficient mussel assemblage were as follows: 16 Species-100% accounted (300 minutes searched), 19 Species-100% accounted (120 minutes searched), 27 Species- 92.5% accounted (254 minutes searched), 28 Species- 78.5% accounted (120 minutes searched). Though, these numbers are based on populations with diversities and densities greater than the Monongahela River. The total number of searched minutes by divers in the Monongahela River in 2008 was 1,860 minutes. By generalization, the 7 species found in the Monongahela River in 31 hours search time is sufficient sample time for complete species assemblage but scientific validation on large rivers is limited at this time.

Figure 7 illustrates the cumulative number of mussels species found compared to the total number of individuals collected. This graph in time series shows that gradually over time the asymptote of the number of species found gradually levels off indicating that the likely of finding more species is low. This graph illustrates that it is possible that one or two more species may be residing within the Monongahela River proper within Pennsylvania. Figure 8 also illustrates that one or two species may be possible with the addition of 10 to 20 more man hours of search time above the 31 hours conducted during this survey.

TABLE 6. Mussel species collected on the Monongahela River proper by various surveyors from the complete list of mussels collected from the Monongahela River basin to date.

Surveyor	Ortmann (1919)	Tolin (1987)	Bogan (1993)	Marshall University (2008)
Location	Monongahela River [A] (PA & WV)	Monongahela River [1] (PA)	Monongahela River [2] (PA)	Monongahela River [3] (PA)
Actinonaias ligamentina	x			
Alasmidonta marginata				
Amblema plicata				x
*Cyclonaias tuberculata**				
*Ellipsaria lineolata**	x			
Elliptio complanata[4]				
*Elliptio crassidens**	x			
Elliptio dilatata	x			
Epioblasma triquetra				
Fusconaia flava	x			
Fusconaia subrotunda	x			
*Lampsilis abrupta**	x			
Lampsilis cardium	x			
Lampsilis fasciola				
Lampsilis radiata[4]				
Lampsilis siliquoidea	x			x
Lasmigona compressa				
Lasmigona costata	x			x
Leptodea fragilis	x			x
Ligumia recta	x			
*Obliquaria reflexa**	x			
*Obovaria subrotunda**	x			
Plethobasus cyphyus	x			
Pleurobema clava				
*Pleurobema cordatum**	x			
*Pleurobema rubrum**	x			
Pleurobema sintoxia				
Potamilus alatus	x			x
Ptycobranchus fasciolaris	x			
Pyganodon cataracta[4]				
Pyganodon grandis	x			x
Quadrula cylindrica	x			
*Quadrula metanevra**	x			
*Quadrula pustulosa**	x			
Quadrula quadrula				x
Simpsonaias ambigua				
Strophitus undulatus	x			
Tritogonia verrucosa	x			
Utterbackia imbecillus				
Villosa iris				
Total taxa	25	0	0	7

* Presumed extirpated from Pennsylvania (Bogan 1993)
[1] Survey conducted only in the lower 41.5 miles of the Monongahela River
[2] Survey conducted at 6 sites on Monongahela River
[3] Survey conducted at 31 sites over 91 miles on Monongahela River
[4] Noted from Bogan (1993) as introduced species from Atlantic slope drainage
[A] Does not include archaeological taxa collected from shell middens (Ortmann 1909)

TABLE 7. Mussel species collected from tributaries of the Monongahela River within Pennsylvania and West Virgina by various surveyors from the complete list mussels collected in the Monongahela River basin to date.

Surveyor	Ortman (1919)	Dennis (1971)	Zeto (1982)	Bogan (1993)
Location	Monongahela Tributaries (WV & PA)	Monongahela Tributaries (PA)	Monongahela Tributaries (WV)	Monongahela Tiributaries (WV & PA)
Actinonaias ligamentina	x			
Alasmidonta marginata	x			
Amblema plicata	x		x	x
*Cyclonaias tuberculata**	x			
*Ellipsaria lineolata**				
Elliptio complanata[1]				x
*Elliptio crassidens**				
Elliptio dilatata	x		x	x
Epioblasma triquetra	x		x	x
Fusconaia flava	x		x	x
Fusconaia subrotunda	x	x		
*Lampsilis abrupta**				
Lampsilis cardium	x		x	x
Lampsilis fasciola	x			x
Lampsilis radiata[1]			x	x
Lampsilis siliquoidea	x	x		x
Lasmigona compressa				x
Lasmigona costata	x	x	x	x
Leptodea fragilis				
Ligumia recta	x			
*Obliquaria reflexa**				
*Obovaria subrotunda**			x	
Plethobasus cyphyus				
Pleurobema clava	x		x	
*Pleurobema cordatum**				
*Pleurobema rubrum**				
Pleurobema sintoxia	x		x	x
Potamilus alatus	x			
Ptycobranchus fasciolaris	x		x	x
Pyganodon cataracta[1]				x
Pyganodon grandis	x	x	x	x
Quadrula cylindrica				
*Quadrula metanevra**				
*Quadrula pustulosa**	x			
Quadrula quadrula				
Simpsonaias ambigua			x	x
Strophitus undulatus	x	x	x	x
Tritogonia verrucosa	x		x	x
Utterbackia imbecillus				x
Villosa iris	x			x
Total taxa	22	5	16	20

* Presumed extirpated from Pennsylvania (Bogan 1993)
[1] Noted from Bogan (1993) as introduced species from Atlantic slope drainage

2. CHAPTER II: Evaluation of the ORSANCO Copper Pole Substrate Sampling Technique Using G.I.S. Interpolation techniques

2.1 INTRODUCTION

As humans continue to inhabit areas in close proximity to water, their inherent anthropogenic activities routinely degrade waterways, estuaries and aquatic systems. These aquatic ecosystems are extremely vulnerable to habitat modification, pollution, and exploitation. Appropriate policies and strategies for maintaining waterway health becomes the framework for improvement. These improvements must be based upon reliable and accurate data from the field placed unto scientific record (Diaz et al., 2004).

A key component of ecological integrity is habitat. Habitat can be defined as the complete physical and chemical environment of an aquatic ecosystem and its associated living organisms. Standard Rapid Bioassessment Protocols from various administrative organizations such as the EPA, consider habitat to be the physical setting in which any organism resides (Shaver et al., 2007). Naturally, a primary component of any aquatic ecosystem is substrate consistency and composition. Key components for numerous aquatic organisms, such as mussels, insects, and fish, is substrate composition and bedload consistency. Substrate also is considered the variety of natural underwater structures in the aquatic environment such as woody debris, undercut banks, boulders, cobble, sediment or any other natural area. These environments are key locations for spawning and nursery functions required for macrofauna integrity (Shaver et al., 2007).

Substrate characterization examines the type, condition, and relationship of benthic environments. These relationships often revolve around characterizing the particular sediment composition in terms of bedrock, boulder, cobble, gravel, sand, and fines. Benthic substrates have received limited research when compared to agriculture and surface soils, which have had much work done on sediment characterization in relation to toxicity to classify, quantify, and identify their characteristics. Lack of in-depth benthic substrate research is inherently due to difficulties associated with conducting research on areas underneath the water surface.

Severe declines in benthic organisms and composition has ignited recent research efforts to thoroughly examine the effects which anthropogenic activities are having in the waterways worldwide. Habitat monitoring and evaluation has become a standard in aquatic research. Biological integrity cannot be directly determined through habitat or substrate monitoring alone but can be used as a means to understand impacts associated with harm or degradation in aquatic ecosystems (Shaver et al., 2007).

Various techniques can be utilized to monitor benthic substrate and habitats which range from extremely intensive to near simplistic. Depending upon the objectives sought, researchers must determine the best means of evaluation. Factors that attribute to different sampling techniques include time, money, man power, and purpose. A researcher evaluating the impacts of agriculture runoff may look for accumulation of fines or sand. Whereas, a biologist looking for suitable habitat for a rare mussel may concentrate on substrate compositions 25 centimeters below substrate surface. Benthic mapping is a common technique used for commercial applications in pipeline or cable laying within the fields of environmental engineering and hydrology. Planners have turned to technology to visually analyze benthic environments by utilizing computer assisted mapping technologies. These advances in technology have allowed scientists to map benthic environments in similar manner as geologists have with topography or land use.

Benthic mapping has become common in the last decade through advances in technology. Geospatial analysis using Geographic Information Systems has become an interdisciplinary endeavor allowing scientists to integrate physical, biological and chemical properties onto a computer generated map. These advances in technology have allowed integrated analysis techniques to examine complex relationships in benthic habitats (Andrews 2003).

Benthic mapping requires collecting reliable data at specific points and connecting that with accurate location data. Various techniques can be used to attain benthic data and largely depends upon research objectives. Some common forms of attaining benthic data include aerial remote sensing and sonar remote sensing. Aerial data acquisition involves using satellite, plane, or helicopter composite data in often broad spectrum electro-optical datum. Aerial photography is limited based upon water clarity, fragmentation and scale (Waddington and Hart 2003). Sonar-based data acquisition involves water based sensing platforms. Sonar sensing platforms are largely dependent upon acoustic relay signal acquisition to estimate seabed composition. In all cases of sonar benthic data acquisition, data must be coupled with extensive ground level data for accuracy. This ground level data involves actual grab samples, video, or core samples to interpret and validate acoustic signaling. Acoustic benthic profiling instruments also require signal amplifiers, a PC, and specialized software for interpretation. This specialized interpretation mandates that special training and equipment must be acquired at often excessive monetary cost (Andrews 2003); (Waddington 2003).

A solution to this expensive and time consuming data ordeal was implemented by the Ohio River Valley Water Sanitation Commission (ORSANCO). ORSANCO's time and cost effective solution for benthic data acquisition is copper pole substrate sampling. The protocol for this techniques is outlined in the ORSANCO Standard Operating Procedures for Physical

Habitat as described in *Development of a Probability-Based Monitoring and Assessment Strategy for Select large Rivers within US EPA Region 5* (Emery et al. 2003). Assessment for collection of bottom sediments is as the following. A 10 ft ¾ inch copper pole is used to probe substrate composition from a vessel. Two ten foot poles can be used with a male/female adapter to extend substrate sampling to 20 foot depths. The probing researcher records each probe of substrate composition, of what the first substrate felt is, followed by second substrate, then third and so on until all substrate compositions are accounted for. Depth is also recorded for each substrate probe. The substrate categories include bedrock, boulders, cobbles, gravel, sand, and fines. This technique is used in a 6 by 11 rectangular grid where a 100 foot transect is made perpendicular to the shore. Each transect is spaced 100 meters apart. A total of 66 data points are taken to characterize the benthic substrate. This technique was implemented for use on the Ohio River and has been adapted by other agencies such as the Pennsylvania Department of Environmental Protection as well as the Ohio Environmental Protection Agency. This method is extremely cost efficient as well as time saving. Little specialized training is needed to sample and no software, amplifiers, PC's or sonar instrumentation is needed. This makes copper poling a very attractive alternative to heavily involved benthic mapping techniques.

To date, to the authors knowledge, no research has been published on the accuracy or efficacy of the ORSANCO Copper Pole Substrate Sampling Technique. The purpose of this study is to investigate the accuracy of the ORSANCO copper pole technique using scuba diver correspondence and geographical information systems.

2.2 METHODS OF INVESTIGATION

31 river sites on the Monongahela River within Pennsylvania were sampled in the Summer of 2008 for substrate composition using a modified version of the ORSANCO Copper pole method. In addition to Copper pole sampling each sampling location (Site) was sampled 12 times at random by SCUBA. Dives were made at random with the directive of 4 dives along the shore (6 feet of water or less), 4 along the river slope, and 4 within the river channel. Each dive was conducted in parallel with the barge channel to avoid complications with ongoing commercial river traffic. Each dive was timed for 5 minute transect surveys. Divers recorded transect length and substrate composition upon return to dive vessel by use of an incremented dive reel and underwater data tablet. Substrate composition was categorized in 5% increments of bedrock, boulder, cobble, gravel, sand and fines. Substrate sizes were defined as follows Bedrock (8000-4000mm), boulder (4000-250mm), cobble (250-64mm), gravel (64-2mm), sand (2-.06mm), and fines (.06-.001)(USEPA, 1998). Upon return to the dive vessel, the dive recorder would document reported substrate compositions.

The 31 sites from the 2008 survey were sampled using ORSANCO's Copper pole technique at random intervals to evaluate against the non-associated random dive locations. Copper Pole points were randomized across the entire site as possible with limitations of depth and commercial barge traffic. The Copper Pole technician reported in sequence the first, second, third, and so on types of substrate felt. Substrate compositions felt by sampling technician were recorded in 5% increments in similar manner as dive substrate protocol. GPS location data was recorded for each dive transect and Copper pole sampling point.

Of the 31 sites, six river sites were randomly selected to represent one site per pool for further substrate evaluation. In order to create a common ground between varying substrate compositions and substrate size classes, the median geometric mean of each substrate class was calculated for comparison. Because each site had a varying degree of different sized geometric substrates, the log of the geometric mean was used to characterize the likelihood of the average substrate size based upon three dimensional averaging. Median substrate size characterizes bedload transport as well as habitat (Smith, 2005). The geometric mean average formula is as follows.

2.2.1 Geometric mean calculation:

$$\text{Geometric Mean} = ((X_1)(X_2)(X_3)........(X_N))^{1/N}$$

Where X= Median Substrate Size for Class, i.e. Cobble, Gravel, Sand..etc.

N= 20, based upon 5% increments or 20 parts per substrate sample

TABLE 8. Substrate size class distribution by millimeter, geometric mean of substrate size class and the log transformed value.

Substrate Class	Size (mm)	Geometric mean	Log_{10} of Geom. mean
Bedrock	8000-4000	5656.85	3.7527
Boulder	4000-250	1000.00	3.000
Cobble	250-64	126.49	2.1020
Gravel	64-2	11.31	1.0536
Sand	2-0.06	0.35	-0.4604
Fines	0.06-0.001	0.00775	-2.1109

Source:(USEPA, 1998)(Smith, 2005)

The median of each substrates category, i.e. Bedrock, boulder, cobble..etc., was used for evaluation. Analysis was based upon 5% increments or 20 parts per sample. This allowed varying substrate compositions to be compared. The median geometric mean for each site was normalized using the log of 10 known as the LD_{50} (Smith 2005).

These normalized data were then used to create a raster diagram with ArcGIS 9.3 interpolation. Using Inverse Distance Weighting (IDW) interpolation, a benthic map was created of the log of geometric means from the randomized copper pole data from each site. IDW technique was then used to estimate unknown points by spatial coordination with the nearest points to statistically estimate the substrate values at the diver assessment locations. These derived points were calculated across a given quadrant area to produce a raster diagram map of benthic substrate based on Copper Pole substrate sampling. The created benthic grid represented a bathymetric mapping model of the river floor which could be referenced against diver reconnaissance. These maps were then cut using ArcGIS 9.3 Arc Edit masking to scientifically compare diver substrate reports to Copper pole sampling.

Interpolated values of the created raster diagram were extracted at each of the 12 dive sites for statistical comparison. Statistical software SPSS version 17.0 was utilized to compare GIS interpolated values to actual diver reported substrate samples. The large number of copper pole sampling points created a layered grid in which the ArcGIS spatial analyst could derive the inferred points between sampling points. Compared to the number of copper pole sampling points the dive substrate locations were too sparsely located, at 12 dives per site, to adequately represent benthic substrate across the entire sampling site. For this reason, the derived copper pole benthic map was used as a base layer to extract derived copper pole values at the same locations divers visually assessed substrate values. At the sampling locations 12 dives were made at each station except for Site 5, where 13 dives were incidentally conducted. The 13th dive was calculated into the sampling sets, the same as the dive data from the other stations.

2.2.2. STATISTICAL TESTING

2.2.2.1 Paired Samples Test

A dependent T-test was utilized in statistical comparison for analysis based on matched pairs of the sampling techniques. The extracted geometric mean substrate value derived from the ArcGIS extrapolated substrate field and the visually reported geometric substrate mean value were tested against each other to compare similarities between sampling techniques using statistical software SPSS version 17. Of the six randomly selected river sampling sites, there were 73 sampling locations. Each diver sampling location was dependently tested against the ArcGIS substrate derived from Inverse Distance Weighted Copper Pole Substrate values. This novel approach allowed the Copper Pole Sampling technique to be statistically compared to visually assessed substrate values to identify the validity of the Copper Pole technique to accurately depict substrate.

2.2.2.2 Wilcoxon Test

Each sampling point of the 6 selected river sites, n=73, was analyzed as a random sampling point independent of other points. This non-parametric technique allowed the data to be analyzed as matched pair samples in a repeated-measures design, making each sampling techniques measured value dependent to each sample point. Testing the magnitude of difference between the pairs of substrate values attained during sampling event. Testing the null hypothesis that if there was no difference between sampling methods then the expected rank sums for positive and negative ranks would be the same. The Wilcoxon signed ranks test avoids the assumption that the data has a normal distribution because it is based on rank order of differences rather than actual value of the differences. For this test, assumption that the distribution of differences is symmetric is still necessary (Crichton 1998).

The derived LD_{50} of each sampling point was back calculated to substrate size categories as listed in FIGURE 1. These substrate size categories were assigned ordinal values based upon their substrate categories as follows: Fines=1, Sand=2, Gravel=3, Cobble=4, Boulder=5 and Bedrock=6. These ordinal values were then tested using statistical software SPSS using the Wilcoxon Signed Ranks Test.

2.3 RESULTS

Visual inspection of sampling points depicted in line graph FIGURES 12-14 show variation among diver assessed substrate and the Copper pole sampling points (FIGURE 15&16). From visual analysis it can be seen that the log transformed data points in Figure 3 mimic the actual substrate values depicted in millimeters indicating that log transformation of points was a valid transformation for analysis (FIGURE 12 & 13). Extracted substrate data, plotted as ordinal substrate values indicates similar trends of geometric substrate values as well as log transformed data (FIGURE 14). From the plotting of ordinal substrate values it can be seen that the two samples techniques had varied calculated substrate mean values (FIGURE 3).

2.3.1 Paired Samples T-test Results

73 points were run for statistical comparison using a Paired Samples T-Test. Diver sample and Copper pole samples transformed using $\log_{10}$ had mean value of -0.37930 and 0.71027 respectively. The standard deviation for diver sample was 1.295327 with a standard mean error of 0.151607. The standard deviation for Copper pole Sample was 1.016073 with a standard deviation of 0.118922. The paired samples conducted compared the reported results of substrate at 73 locations based upon the sampling methods of Divers visual assessment and Copper pole technique. The paired samples had a correlation of 0.304 with a significance of 0.009 and a N value of 73 with a 95% confidence interval. The paired differences for the Diver Sample- Copper pole comparison had a lower difference of -1.412012 and an upper difference of -0.767112 at the 95% confidence interval. T-value for this test was -6.736 with 72 degrees of freedom and a 2-tailed significance of 0.000 (TABLE 9).

2.3.2 Wilcoxon Signed Ranks Results

73 ordinal ranks were run for statistical comparison using Wilcoxon Signed Ranks test. The Diver samples were ranked based upon their geometric mean and defined a substrate category based on values shown in TABLE 1. The extracted GIS substrate values were ranked based on their geometric means on the substrate values defined in TABLE 8 at the diver sampled area. This ranking style enabled a degree of separation between exact geometric mean substrate values and the category of which those values fell to further analyze the efficiency of Copper Pole substrate sampling. Of the 73 locations tested, a total of 19 locations showed equal substrate category values, Copper Pole Ordinal Ranking = Diver Assessed Ordinal Ranking. Copper pole sampling ranked 6 substrate values less than Diver assessed substrate values, Copper Pole Ordinal Ranking < Diver Assessed Ordinal Ranking. 48 locations of the ordinal ranking values indicated Copper Pole Sampling was greater than Diver assessed substrate values, Copper Pole Ordinal Ranking > Diver Assessed Ordinal Ranking (TABLE 10). The Sum of Ranks for Negative Ranks was 194.00 with a Mean Rank of 32.33. The Sum of Ranks for Positive Ranks was 1291.00 with a Mean Rank of 26.90 (TABLE 10).

Test statistics for Copper Pole Substrate testing compared to Diver Assessed Substrate ranking indicated a Z value of -4.925 based on negative ranks. Significance values for the Wilcoxon Signed Ranks test for Asymmetrical 2-tailed, Exact Sig. 2-tailed, and Exact Sig. 1-Tailed were all <0.000 with a point probability of 0.000.

2.4 DISCUSSION

2.4.1 Paired Samples T-test

The null hypothesis in this test suggested that the Copper pole substrate classification would equal the diver's visual assessment within the geometric mean class of that substrate. Critical value of the paired t-test for df=72 at 95% confidence interval is 2.00.
To reject null hypothesis then $T \leq -2.00$ or $T \geq 2.00$ would reject null hypothesis. Reported t-value of -6.736 rejects the null hypothesis with a 2-tailed significance [(p-value=0.000) ≤ (0.05 = α)] at df=72.

The significance reported of $P<0.001$ indicates that the chance of difference due to sampling error was 0.000 at a 95% confidence interval. This indicates that the 73 variables tested against one another were significantly different. This takes into account a certain number of givens for the test to be considered viable. One that the use of extraction of Copper pole points from a raster grid plot of derived interpolation points delivers accurate results. The second that differences among sampling investigators was negligible within the sampling event. The wide threshold of substrate classes as seen within TABLE 8, illustrates a wide variance in substrate class which would increase accuracy of the data reported. As in, with a wide variance in substrate classes it is much more likely that two samplers would report a cobble or gravel as the same with six substrate options versus classes based on millimeters or inches and more categories to choose from.

2.4.2 Wilcoxon Signed Ranks

The Wilcoxon signed ranks tests the null hypothesis that the categorical substrate values between two paired sampling technique, Copper Pole sampling and diver assessed substrate values, were the same. Statistical results show that of the 73 pairs, 19 pairs tied with equal substrate categorization. 6 Pairs were found that Copper Pole Sampling were less than diver assessed sampling. 48 pairs were found that Copper Pole to be greater than the diver assessed sampling. With a Z value of -4.925 it was found that the two sampling techniques were statistically different (TABLE 10).

This suggests that the copper pole sampling technique is consistently under ranking the substrate values found in the river. In our study 65.7% of samples were underestimated compared to that of diver assessed substrate using Wilcoxon Signed Ranks (TABLE 10). The two largest categories to be ranked incorrectly were the smallest substrates fines and sand. Comparison between overall substrate consistencies between the two methods shows that fines were reported to be 3% using copper pole sampling versus 37% using diver assessed methods. While sand was underestimated by 14% using the copper pole sampling technique. The consistent underestimating of smaller substrates may be linked to the inherent inability of small substrate sizes to be felt using the copper pole. This suggests that rivers with large amounts of sand or layers of silt may need increased sampling efforts with diver reconnaissance or side-scan sonar to fully evaluate the benthic substrate conditions for scientific research endeavors.

TABLE 9. Paired T test statistical output using Computer Software SPSS v.17 for the 73 sample locations of 6 river sites on the Monongahela River, PA. Substrate sizes of diver reported sampling and copper pole sampling were compared after log transformation.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Diver Sample	-.37930	73	1.295327	.151607
	Copper Pole Sample	.71027	73	1.016073	.118922

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Diver Sample & Copper Pole Sample	73	.304	.009

Paired Samples Test

		Paired Differences		
		Mean	Std. Deviation	Std. Error Mean
Pair 1	Diver Sample - Copper Pole Sample	-1.089562	1.382025	.161754

Paired Samples Test

		Paired Differences	
		95% Confidence Interval of the Difference	
		Lower	Upper
Pair 1	Diver Sample - Copper Pole Sample	-1.412012	-.767112

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	Diver Sample - Copper Pole Sample	-6.736	72	.000

TABLE 10. Wilcoxon Signed Ranks Test statistical output using Computer Software SPSS v.17 for the 73 sample locations of 5 river sites on the Monongahela River, PA. Substrate sizes of diver reported sampling and copper pole sampling were compared after log transformation.

Ranks

		N	Mean Rank	Sum of Ranks
Copper pole Ordinal Ranking - Diver Ordinal Ranking	Negative Ranks	6[a]	32.33	194.00
	Positive Ranks	48[b]	26.90	1291.00
	Ties	19[c]		
	Total	73		

a. Copper pole Ordinal Ranking < Diver Ordinal Ranking

b. Copper pole Ordinal Ranking > Diver Ordinal Ranking

c. Copper pole Ordinal Ranking = Diver Ordinal Ranking

Test Statistics[b]

	Copper pole Ordinal Ranking - Diver Ordinal Ranking
Z	-4.925[a]
Asymp. Sig. (2-tailed)	.000
Exact Sig. (2-tailed)	.000
Exact Sig. (1-tailed)	.000
Point Probability	.000

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Diver Ordinal Ranking	73	2.01	1.061	1	5
Copper pole Ordinal Ranking	73	2.81	.739	1	5

FIGURE 12. Line graph comparison of copper pole sample versus diver assessed sample reported in millimeters of geometric mean.

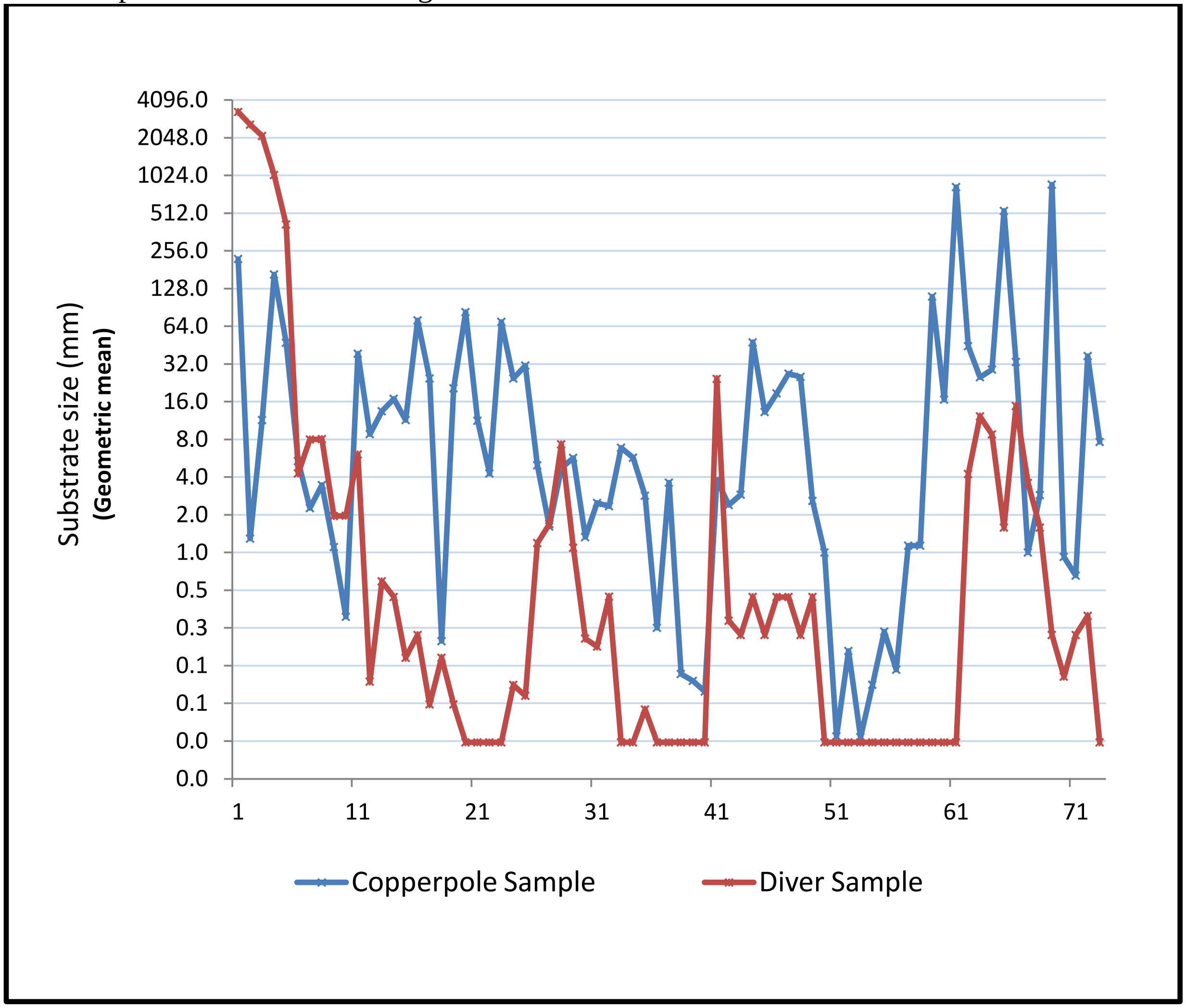


FIGURE 13. Line graph comparison of copper pole sample versus diver assessed sample transformed by log_{10} of geometric mean.

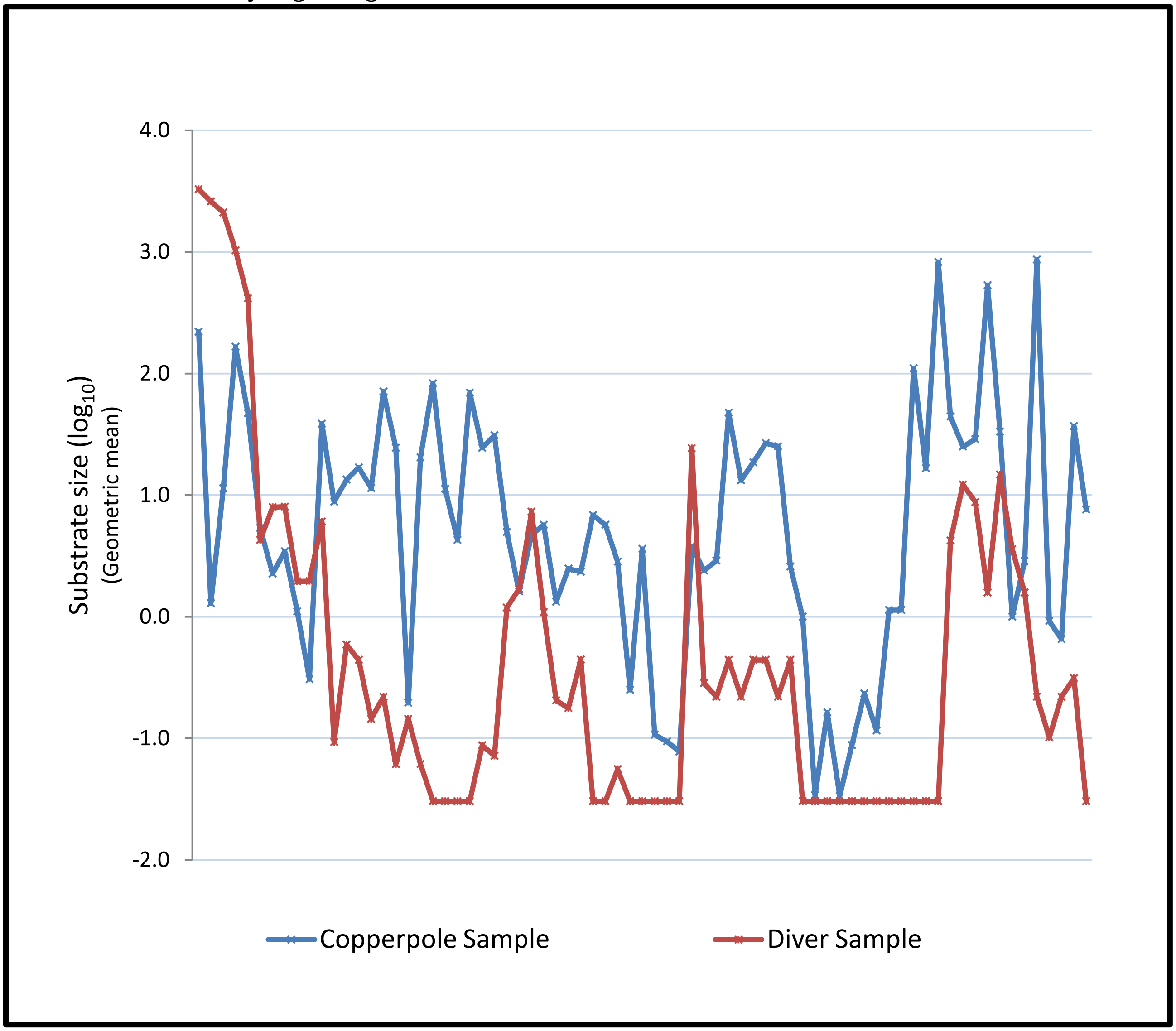


FIGURE 14. Derived Geometric mean data of substrate samples plotted as ordinal values against one another per sampling location.

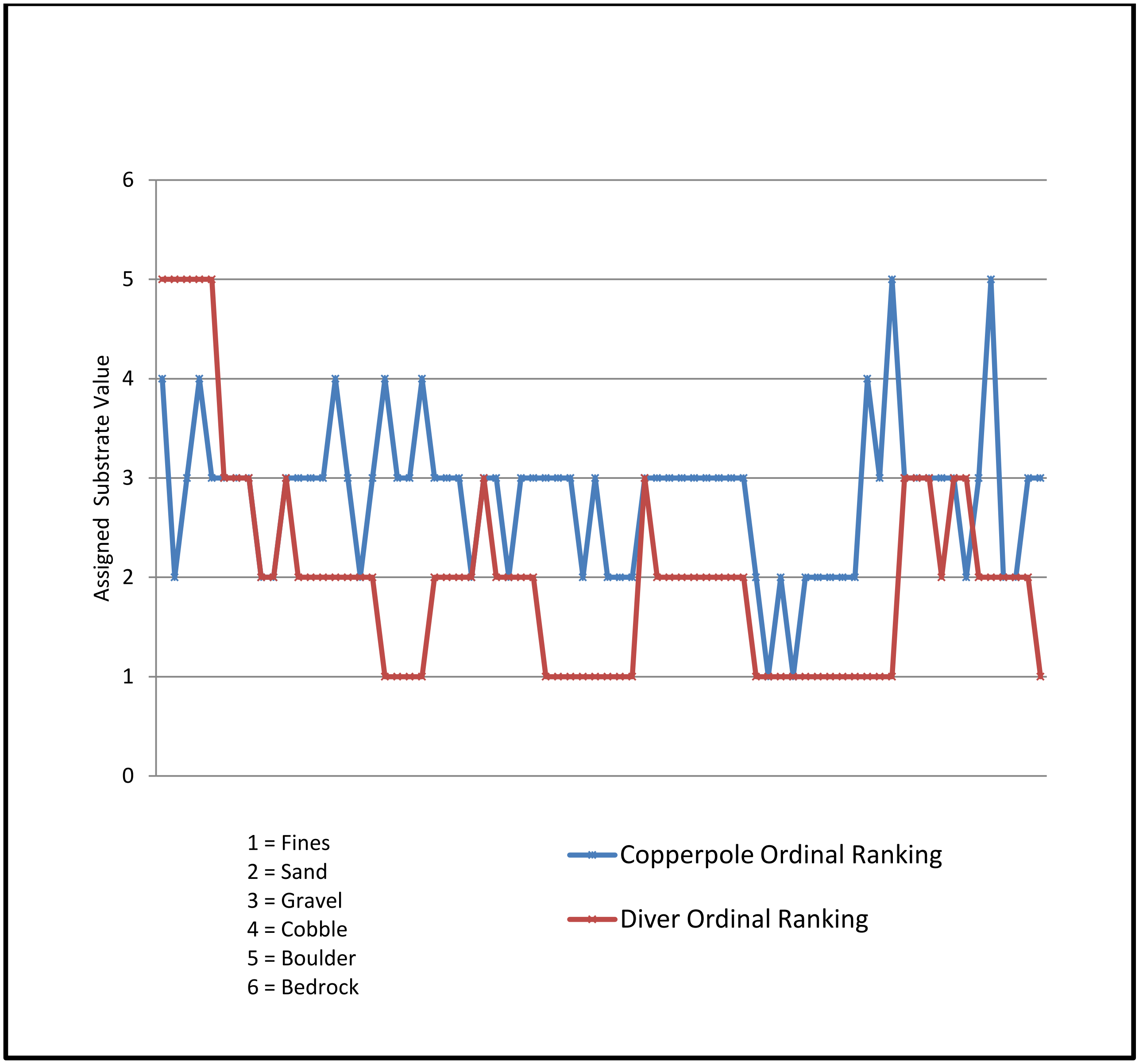


FIGURE 15. Pie chart depicting the substrate geometric mean categories for the 73 points sampled using the copper pole substrate sampling technique.

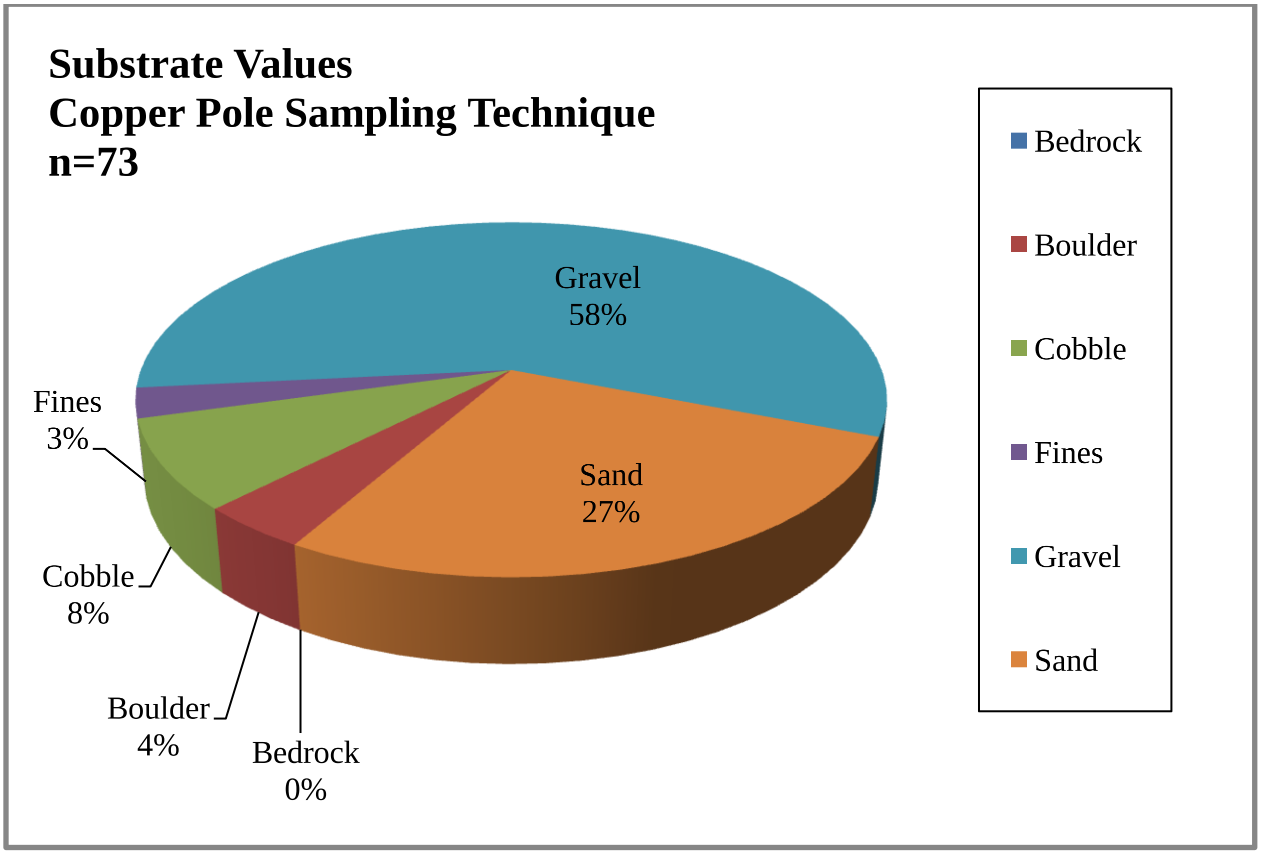


FIGURE 16. Pie chart depicting the substrate geometric mean categories for the 73 points sampled using the diver visual assessment.

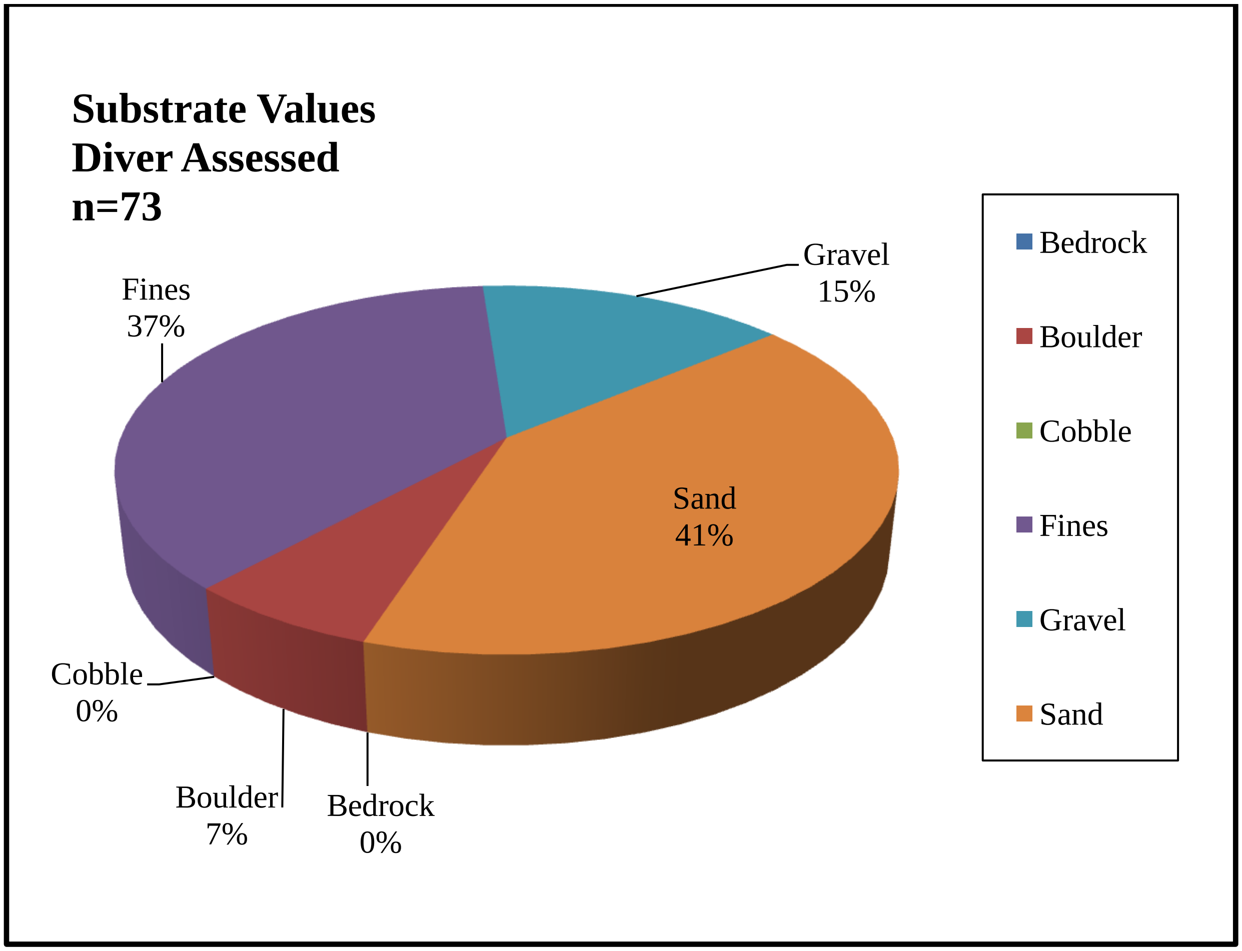


FIGURE 17. Inverse distance weighting interpolation of copper pole data with extracted dive location points

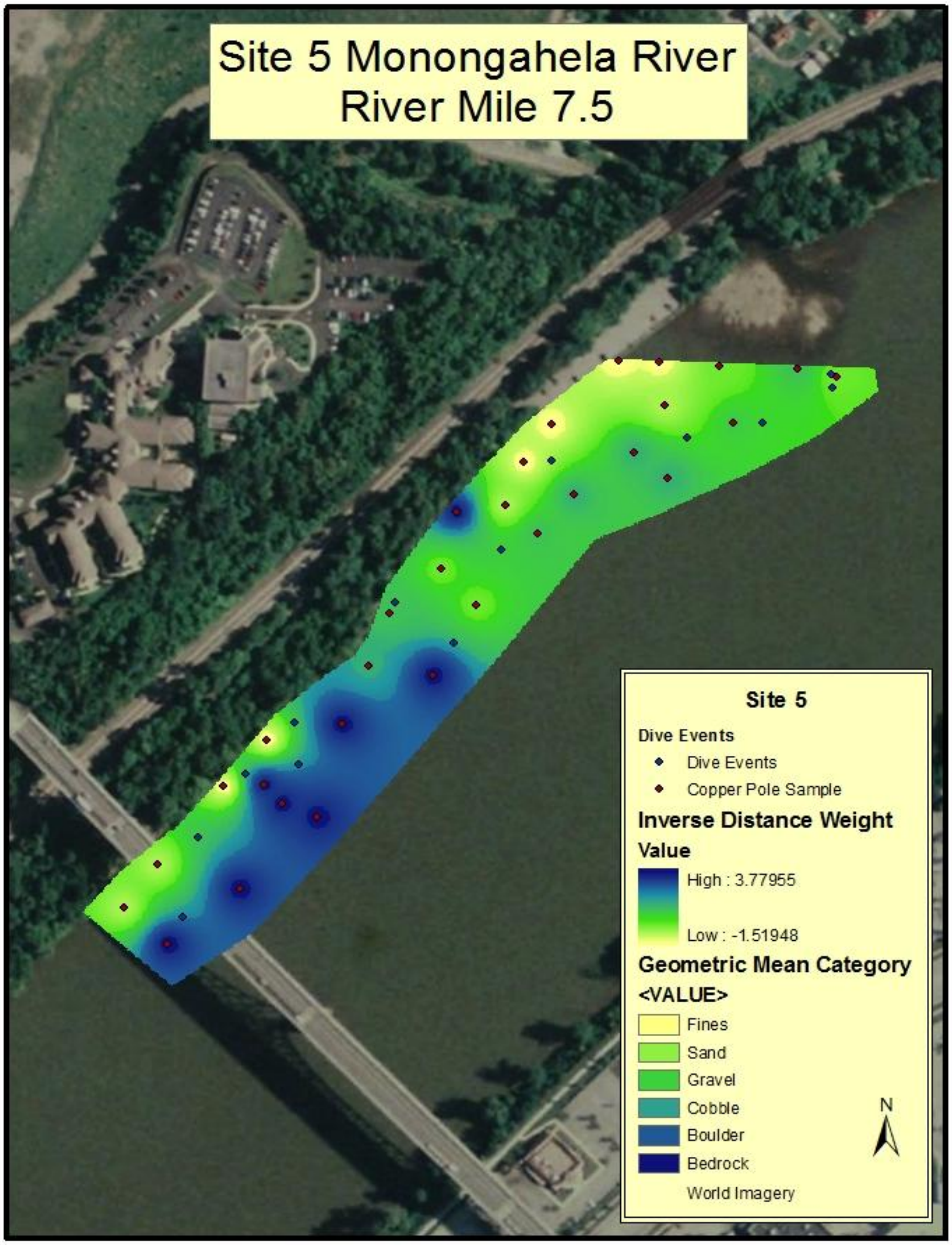


TABLE 11. Site 5 comparison of diver reported substrate composition to copper pole reported substrate composition.

Sample Number	Diver Sample Log Transformed	Substrate Size in mm. (Divers)	Diver Substrate Category	Extracted CopperPole Sample	Extracted Substrate Size in mm. (CopperPole)	Extracted Copper pole Category
1	3.517	3286.590	Boulder	2.343	220.466	Cobble
2	3.416	2604.200	Boulder	0.111	1.292	Sand
3	3.325	2112.110	Boulder	1.057	11.410	Gravel
4	3.013	1030.480	Boulder	2.220	165.828	Cobble
5	2.619	415.590	Boulder	1.674	47.254	Gravel
6	0.631	4.280	Gravel	0.730	5.364	Gravel
7	0.902	7.980	Gravel	0.354	2.262	Gravel
8	0.906	8.045	Gravel	0.538	3.454	Gravel
9	0.291	1.956	Sand	0.043	1.105	Sand
10	0.294	1.967	Sand	-0.513	0.307	Sand
11	0.783	6.069	Gravel	1.587	38.675	Gravel
12	-1.031	0.093	Sand	0.945	8.818	Gravel
13	-0.230	0.589	Sand	1.128	13.431	Gravel

*Green represents diver sample equal to copper pole sample
*Orange represents diver sample unequal to copper pole sample

FIGURE 18. Pie chart depicting diver reported substrate composition of Site 5 Monongahela River, PA.

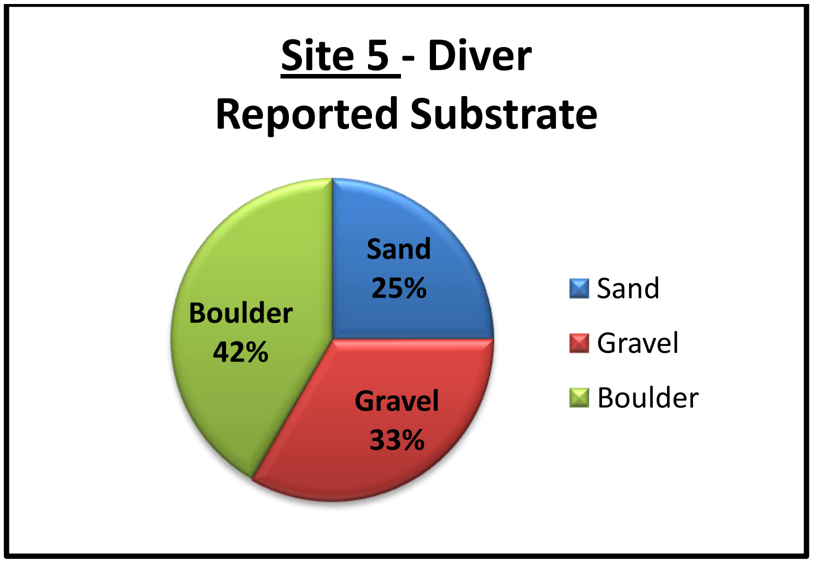


FIGURE 19. Pie chart depicting copper pole reported substrate composition of Site 5 Monongahela River, PA.

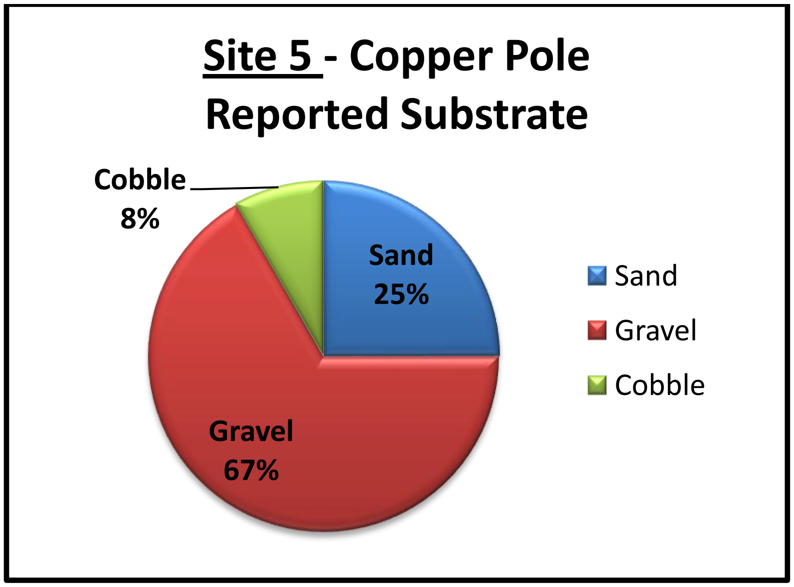


FIGURE 20. Inverse distance weighting interpolation of copper pole data with extracted dive location points for Site 9 Monongahela River, PA.

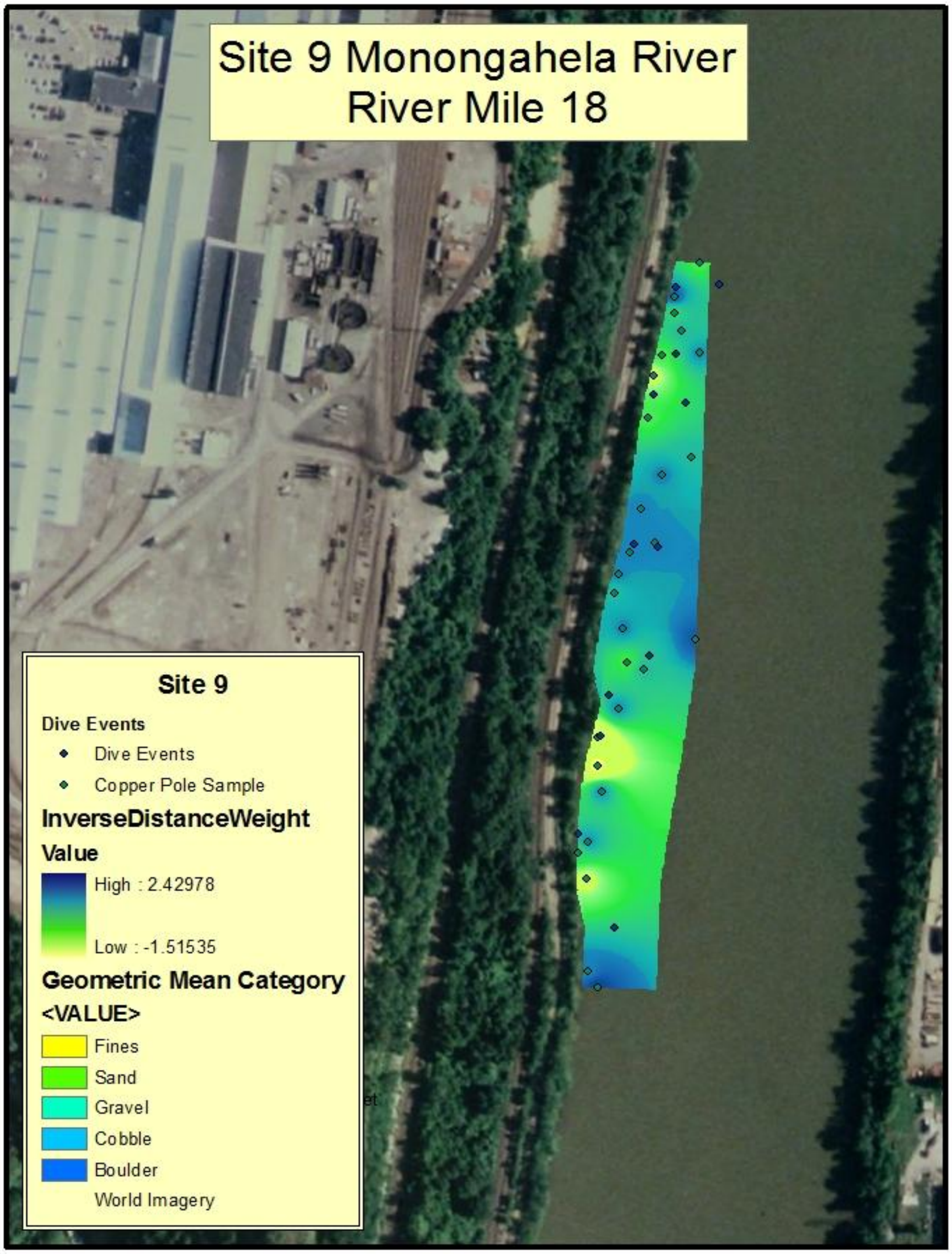


TABLE 12. Site 9 comparison of diver reported substrate composition to copper pole reported substrate composition.

Sample Number	Diver Sample Log Transformed	Substrate Size in millimeters (Divers)	Diver Substrate Category	Copper Pole Sample Log Transformed	Substrate Size mm. (CopperPole)	Extracted Copper Pole Category
1	-0.355	0.442	Sand	1.227	16.879	Gravel
2	-0.840	0.144	Sand	1.058	11.418	Gravel
3	-0.658	0.220	Sand	1.852	71.198	Cobble
4	-1.212	0.061	Sand	1.390	24.526	Gravel
5	-0.840	0.144	Sand	-0.708	0.196	Sand
6	-1.212	0.061	Sand	1.311	20.463	Gravel
7	-1.516	0.031	Fines	1.919	83.015	Cobble
8	-1.516	0.031	Fines	1.052	11.260	Gravel
9	-1.516	0.031	Fines	0.631	4.274	Gravel
10	-1.516	0.031	Fines	1.842	69.430	Cobble
11	-1.057	0.088	Sand	1.389	24.502	Gravel
12	-1.144	0.072	Sand	1.493	31.084	Gravel

*Green represents diver sample equal to copper pole sample
*Orange represents diver sample unequal to copper pole sample

FIGURE 21. Pie chart depicting diver reported substrate composition of Site 9 Monongahela River, PA.

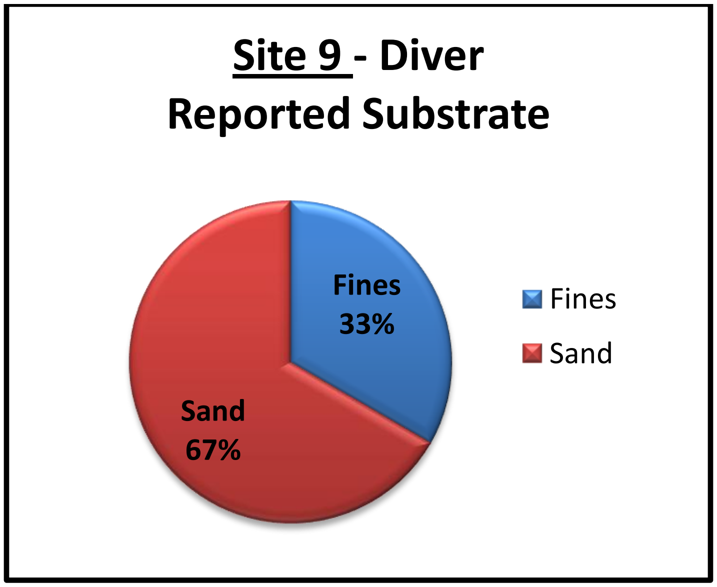


FIGURE 22. Pie chart depicting copper pole reported substrate composition of Site 9 Monongahela River, PA.

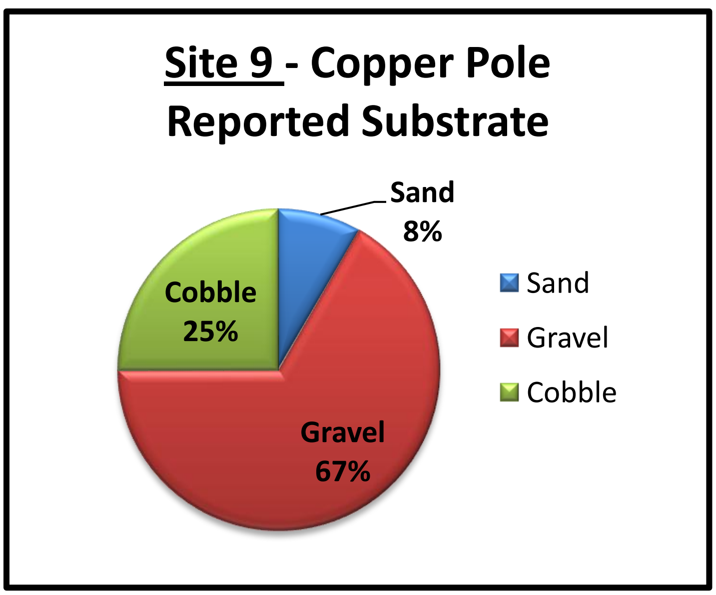


FIGURE 23. Inverse distance weighting interpolation of copper pole data with extracted dive location points for Site 11 Monongahela River, PA.

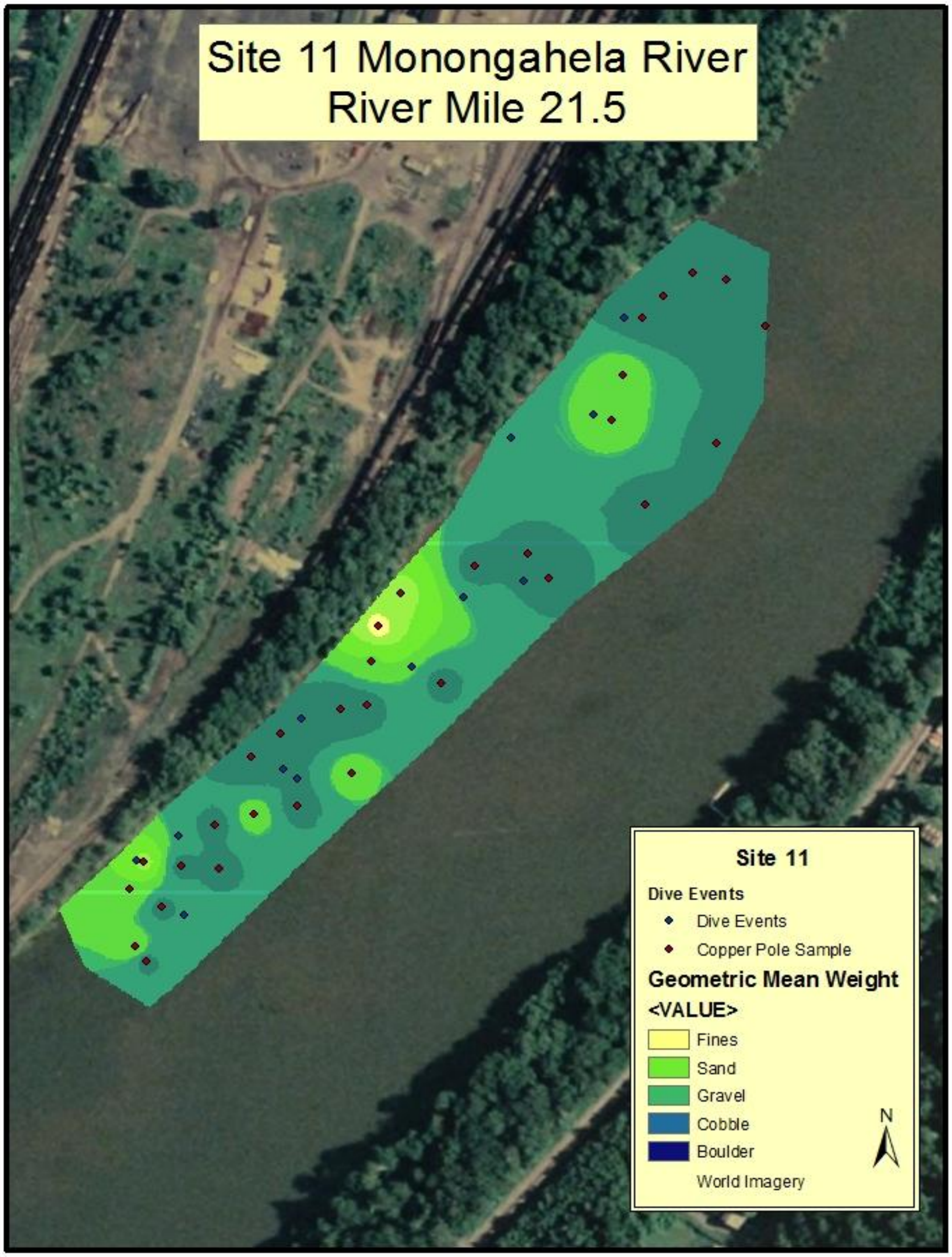


TABLE 13. Site 11 comparison of diver reported substrate composition to copper pole reported substrate composition.

Sample Number	Diver Sample Log Transformed	Substrate Size in millimeters (Divers)	Diver Substrate Category	Copper Pole Sample Log Transformed	Substrate Size mm. (CopperPole)	Extracted Copper Pole Category
1	0.076	1.190	Sand	0.696	4.967	Gravel
2	0.228	1.689	Sand	0.208	1.613	Sand
3	0.864	7.304	Gravel	0.674	4.725	Gravel
4	0.038	1.091	Sand	0.756	5.696	Gravel
5	-0.687	0.205	Sand	0.123	1.327	Sand
6	-0.751	0.177	Sand	0.396	2.488	Gravel
7	-0.353	0.444	Sand	0.370	2.343	Gravel
8	-1.516	0.031	Fines	0.836	6.860	Gravel
9	-1.516	0.031	Fines	0.756	5.707	Gravel
10	-1.253	0.056	Fines	0.453	2.841	Gravel
11	-1.516	0.031	Fines	-0.601	0.251	Sand
12	-1.516	0.031	Fines	0.558	3.611	Gravel

*Green represents diver sample equal to copper pole sample
*Orange represents diver sample unequal to copper pole sample

FIGURE 24. Pie chart depicting diver reported substrate composition of Site 11 Monongahela River, PA.

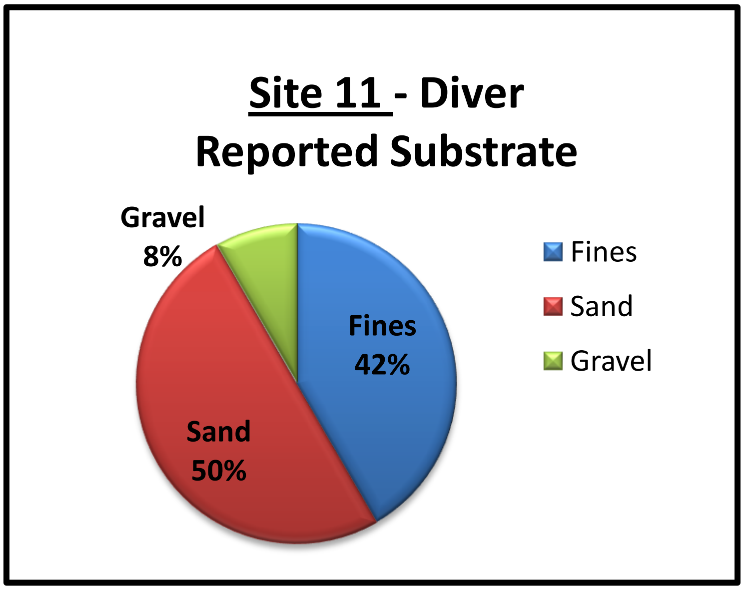


FIGURE 25. Pie chart depicting copper pole reported substrate composition of Site 11 Monongahela River, PA.

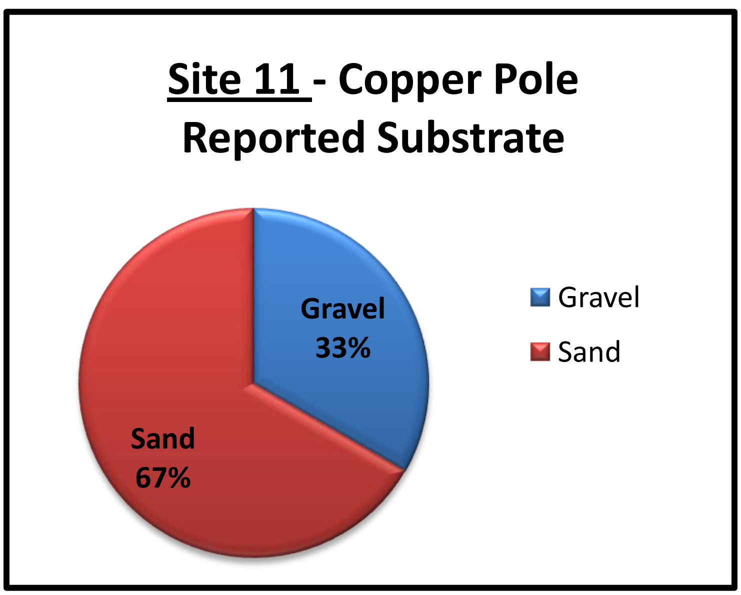


FIGURE 26. Inverse distance weighting interpolation of copper pole data with extracted dive location points for Site 20 Monongahela River, PA.

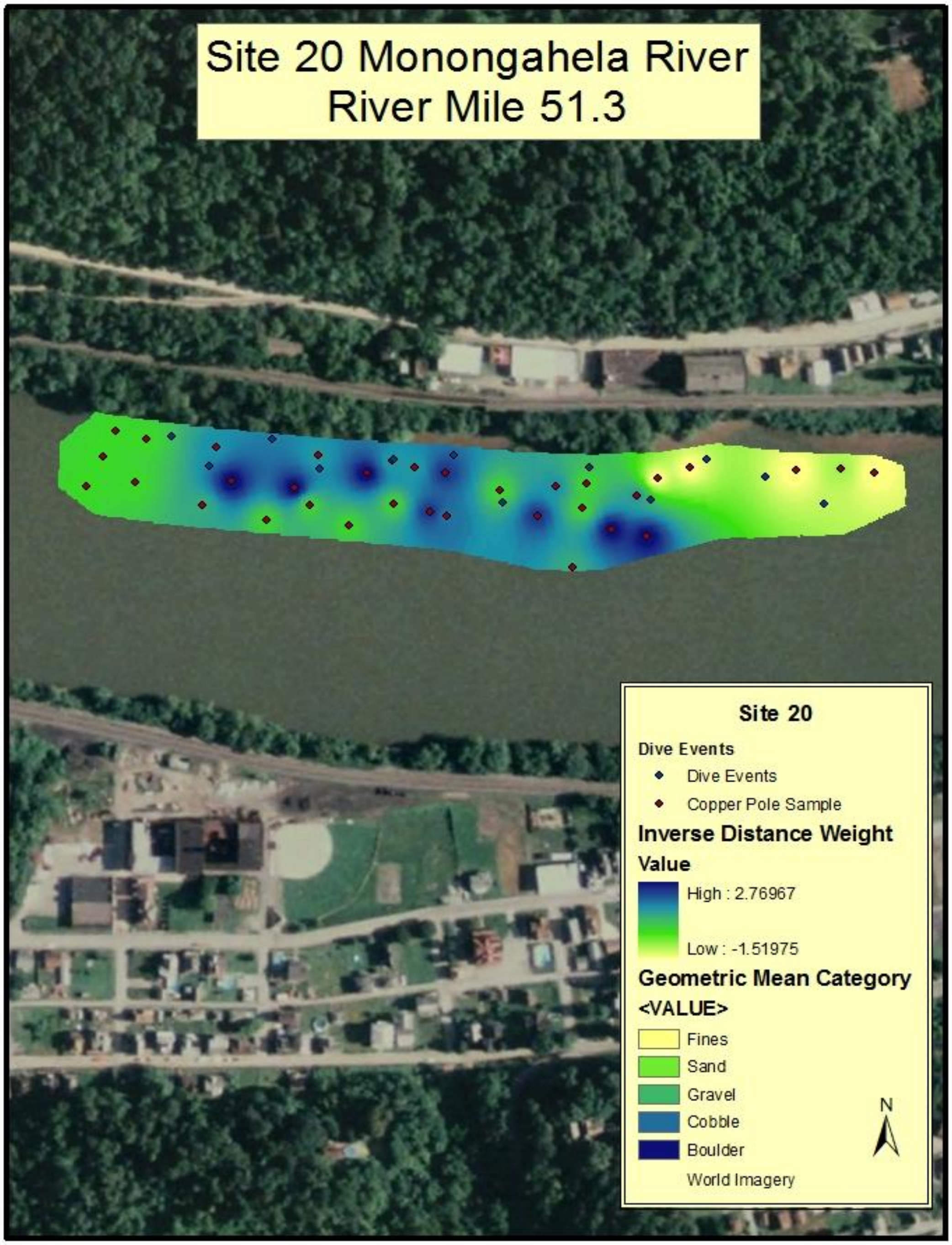


TABLE 14. Site 20 comparison of diver reported substrate composition to copper pole reported substrate composition.

Sample Number	Diver Sample Log Transformed	Substrate Size in millimeters (Divers)	Diver Substrate Category	Copper Pole Sample Log Transformed	Substrate Size mm. (CopperPole)	Extracted Copper Pole Category
1	-1.516	0.031	Fines	-0.970	0.107	Sand
2	-1.516	0.031	Fines	-1.025	0.094	Sand
3	-1.516	0.031	Fines	-1.110	0.078	Sand
4	1.386	24.33	Gravel	0.580	3.804	Gravel
5	-0.545	0.285	Sand	0.379	2.393	Gravel
6	-0.658	0.220	Sand	0.462	2.896	Gravel
7	-0.355	0.442	Sand	1.678	47.61	Gravel
8	-0.658	0.220	Sand	1.122	13.23	Gravel
9	-0.355	0.442	Sand	1.270	18.64	Gravel
10	-0.355	0.442	Sand	1.428	26.79	Gravel
11	-0.658	0.220	Sand	1.402	25.25	Gravel
12	-0.355	0.442	Sand	0.412	2.584	Gravel

*Green represents diver sample equal to copper pole sample
*Orange represents diver sample unequal to copper pole sample

FIGURE 27. Pie chart depicting diver reported substrate composition of Site 20 Monongahela River, PA.

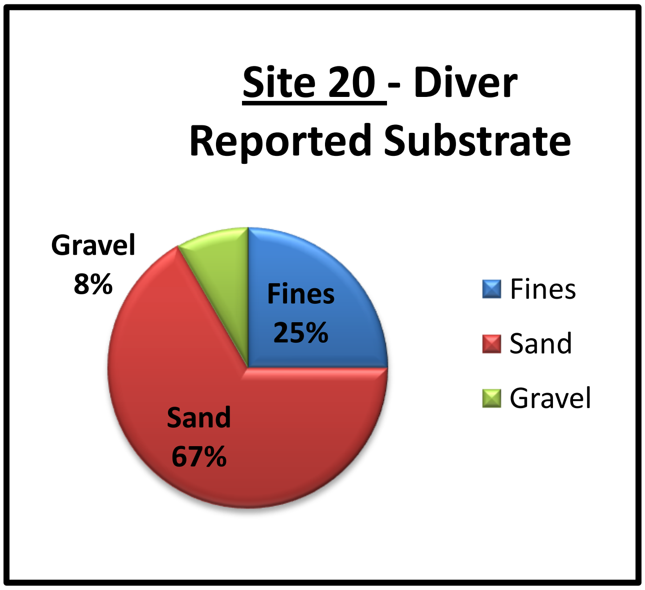


FIGURE 28. Pie chart depicting copper pole reported substrate composition of Site 20 Monongahela River, PA.

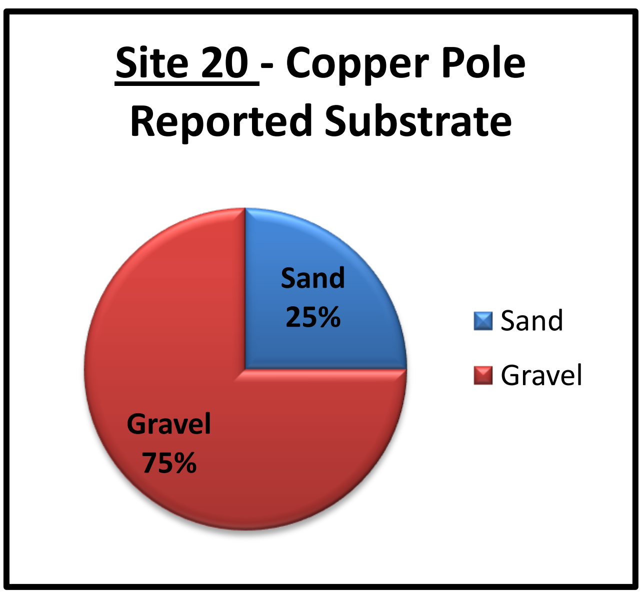


FIGURE 29. Inverse distance weighting interpolation of copper pole data with extracted dive location points for Site 28 Monongahela River, PA.

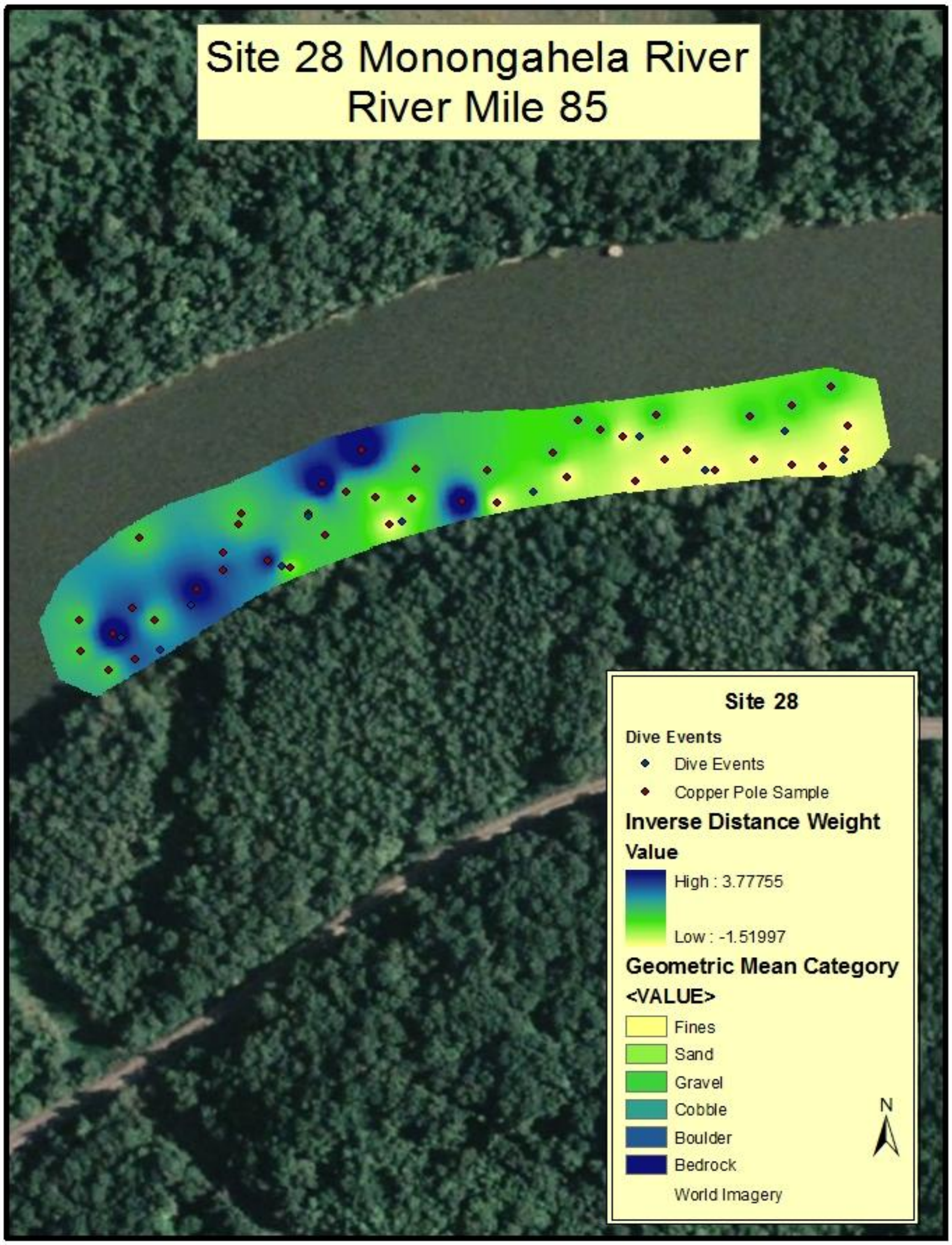


TABLE 15. Site 28 comparison of diver reported substrate composition to copper pole reported substrate composition.

Sample Number	Diver Sample Log Transformed	Substrate Size in millimeters (Divers)	Diver Substrate Category	Copper Pole Sample Log Transformed	Substrate Size mm. (CopperPole)	Extracted Copper Pole Category
1	-1.516	0.031	Fines	0.000	1.000	Sand
2	-1.516	0.031	Fines	-1.468	0.034	Fines
3	-1.516	0.031	Fines	-0.786	0.164	Sand
4	-1.516	0.031	Fines	-1.475	0.034	Fines
5	-1.516	0.031	Fines	-1.056	0.088	Sand
6	-1.516	0.031	Fines	-0.631	0.234	Sand
7	-1.516	0.031	Fines	-0.935	0.116	Sand
8	-1.516	0.031	Fines	0.055	1.135	Sand
9	-1.516	0.031	Fines	0.055	1.134	Sand
10	-1.516	0.031	Fines	2.043	110.495	Cobble
11	-1.516	0.031	Fines	1.221	16.618	Gravel
12	-1.516	0.031	Fines	2.917	826.013	Boulder

*Green represents diver sample equal to copper pole sample
*Orange represents diver sample unequal to copper pole sample

FIGURE 30. Pie chart depicting diver reported substrate composition of Site 28 Monongahela River, PA.

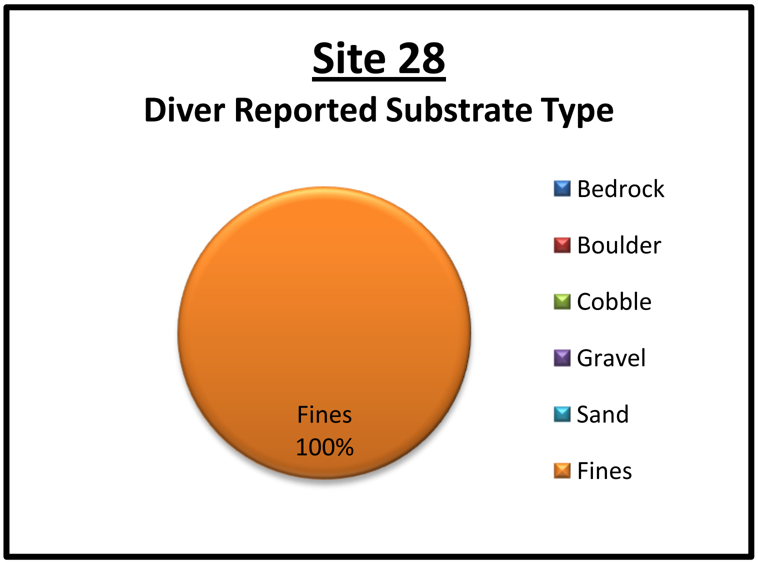


FIGURE 31. Pie chart depicting copper pole reported substrate composition of Site 28 Monongahela River, PA.

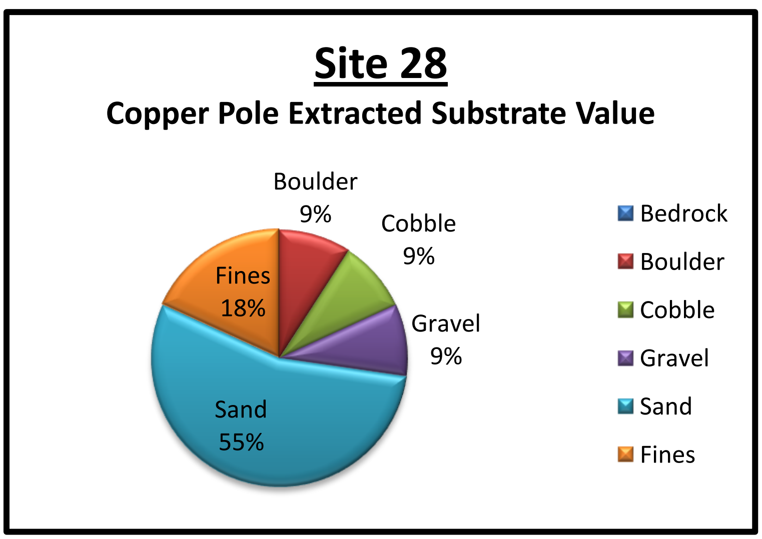


FIGURE 32. Inverse distance weighting interpolation of copper pole data with extracted dive location points for Site 29 Monongahela River, PA.

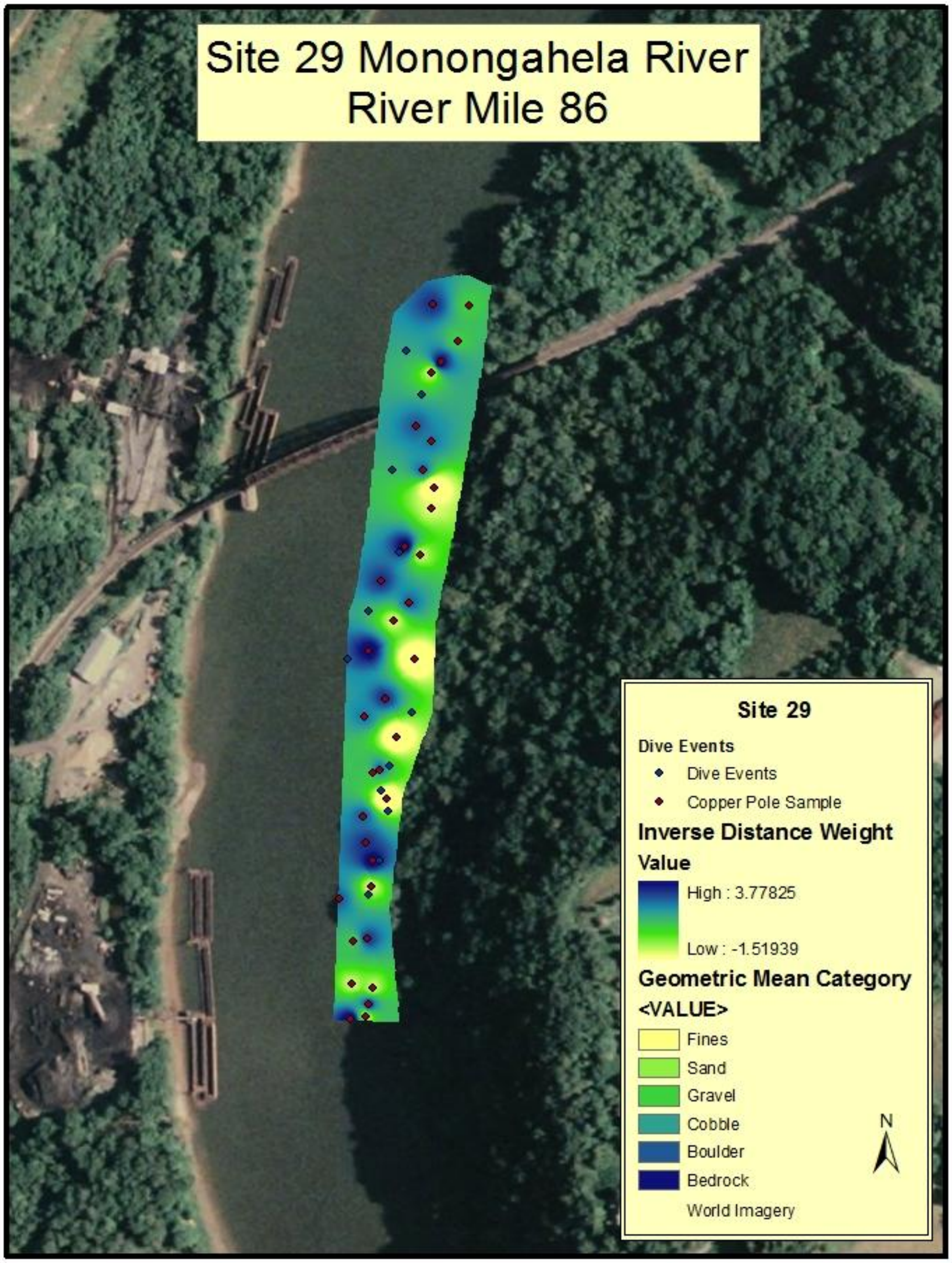


TABLE 16. Site 29 comparison of diver reported substrate composition to copper pole reported substrate composition.

Sample Number	Diver Sample Log Transformed	Substrate Size in millimeters (Divers)	Diver Substrate Category	Copper Pole Sample Log Transformed	Substrate Size mm. (CopperPole)	Extracted Copper Pole Category
1	0.626	4.229	Gravel	1.647	44.35	Gravel
2	1.087	12.21	Gravel	1.399	25.09	Gravel
3	0.943	8.768	Gravel	1.460	28.86	Gravel
4	0.199	1.581	Sand	2.727	533.3	Gravel
5	1.170	14.78	Gravel	1.521	33.21	Gravel
6	0.555	3.592	Gravel	0.000	1.000	Sand
7	0.199	1.581	Sand	0.459	2.875	Gravel
8	-0.658	0.220	Sand	2.937	864.8	Boulder
9	-0.991	0.102	Sand	-0.035	0.922	Sand
10	-0.658	0.220	Sand	-0.184	0.654	Sand
11	-0.505	0.312	Sand	1.568	37.01	Gravel
12	-1.516	0.031	Fines	0.882	7.627	Gravel

*Green represents diver sample equal to copper pole sample
*Orange represents diver sample unequal to copper pole sample

FIGURE 33. Pie chart depicting diver reported substrate composition of Site 29 Monongahela River, PA.

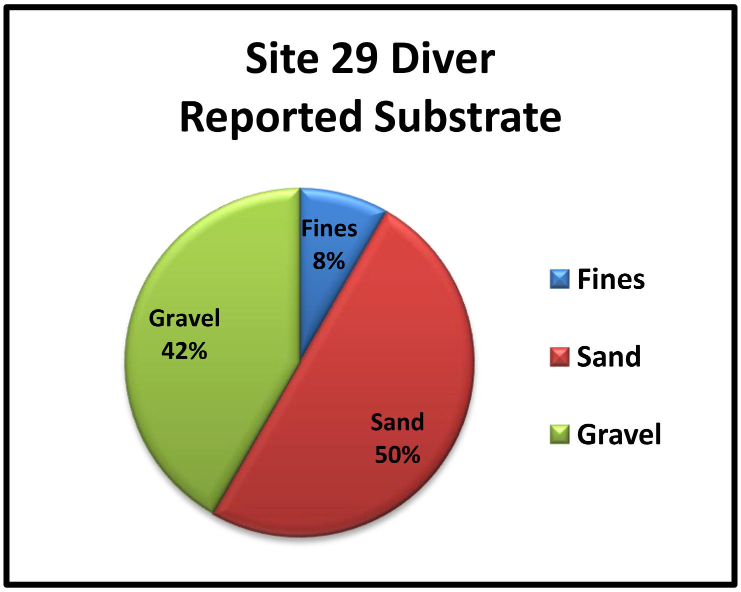


FIGURE 34. Pie chart depicting copper pole reported substrate composition of Site 29 Monongahela River, PA.

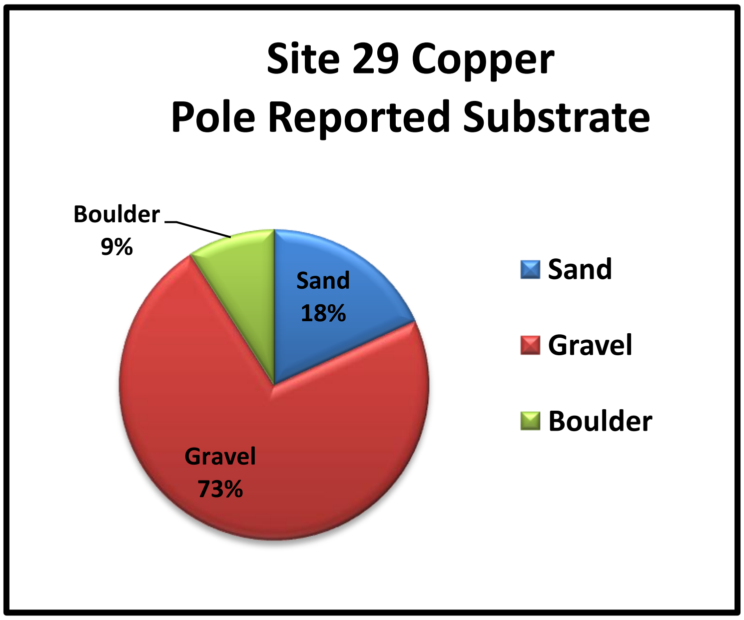


FIGURE 35. Location map of river sampling sites 1-5 in the Braddock Pool of the Monongahela River, PA.

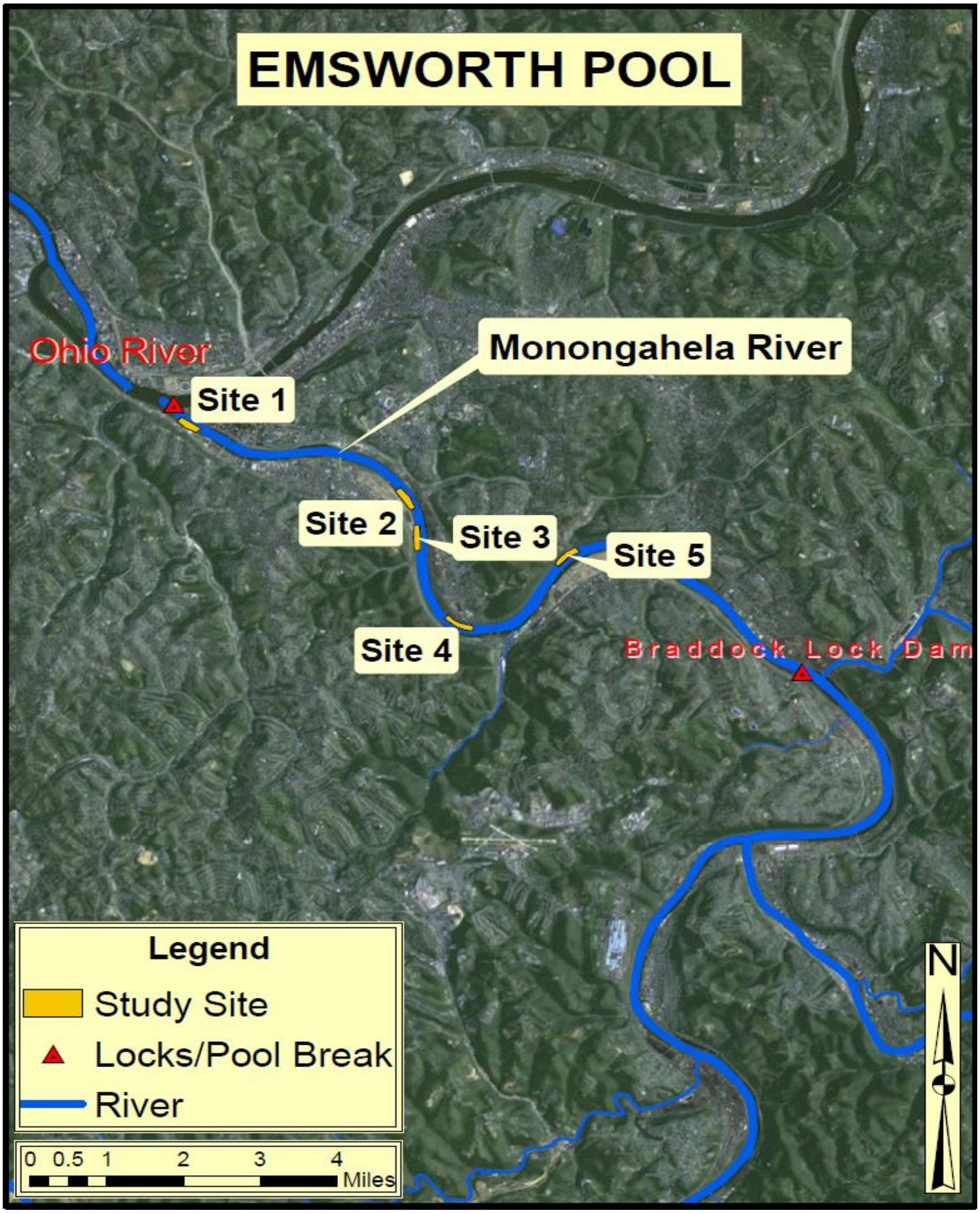


FIGURE 36. Location map of river sampling sites 6-11 in the Braddock Pool of the Monongahela River, PA.

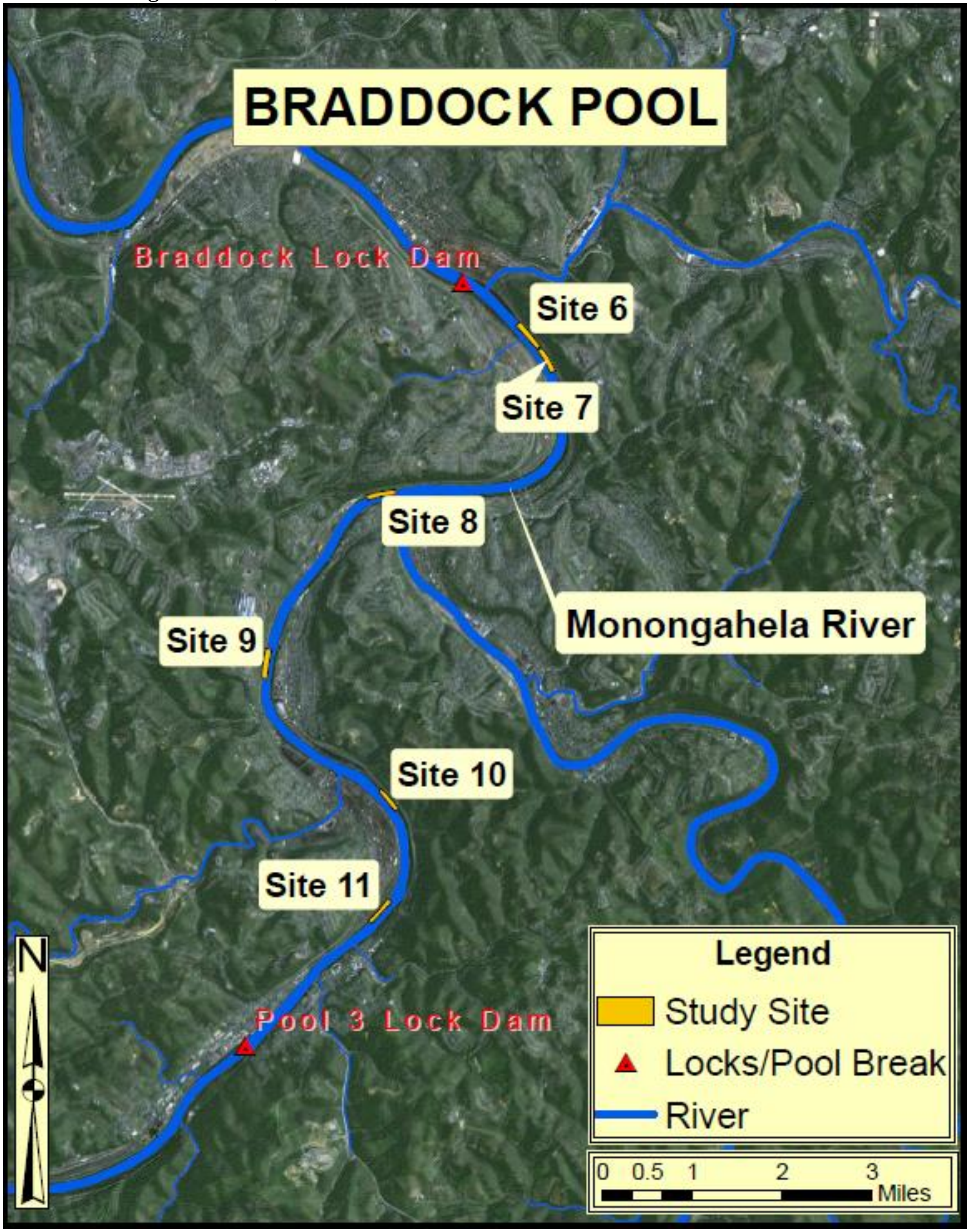


FIGURE 37. Location map of river sampling sites 12-15 in the Pool 3 of the Monongahela River, PA.

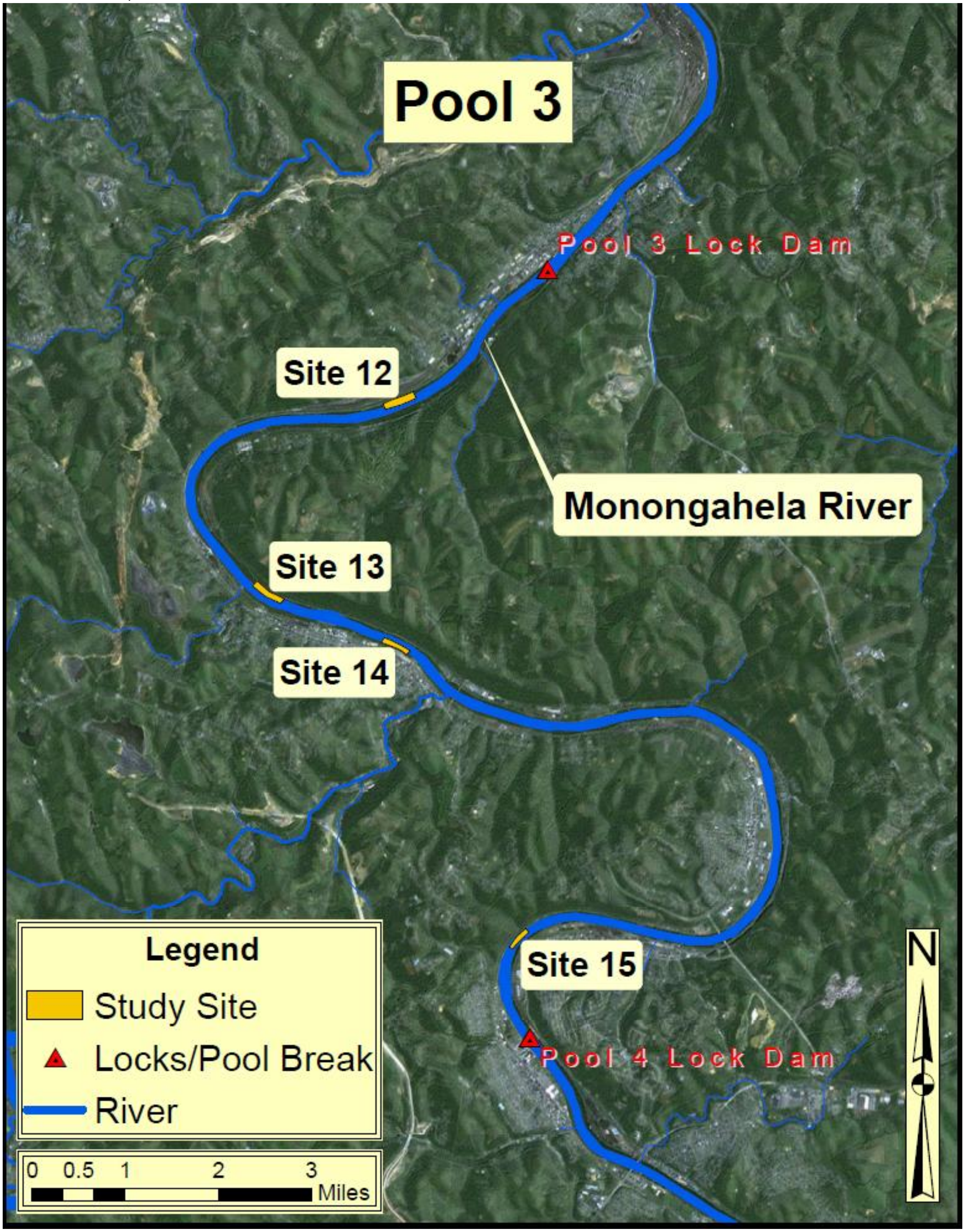


FIGURE 38. Location map of river sampling sites 16-22 in the Pool 4 of the Monongahela River, PA.

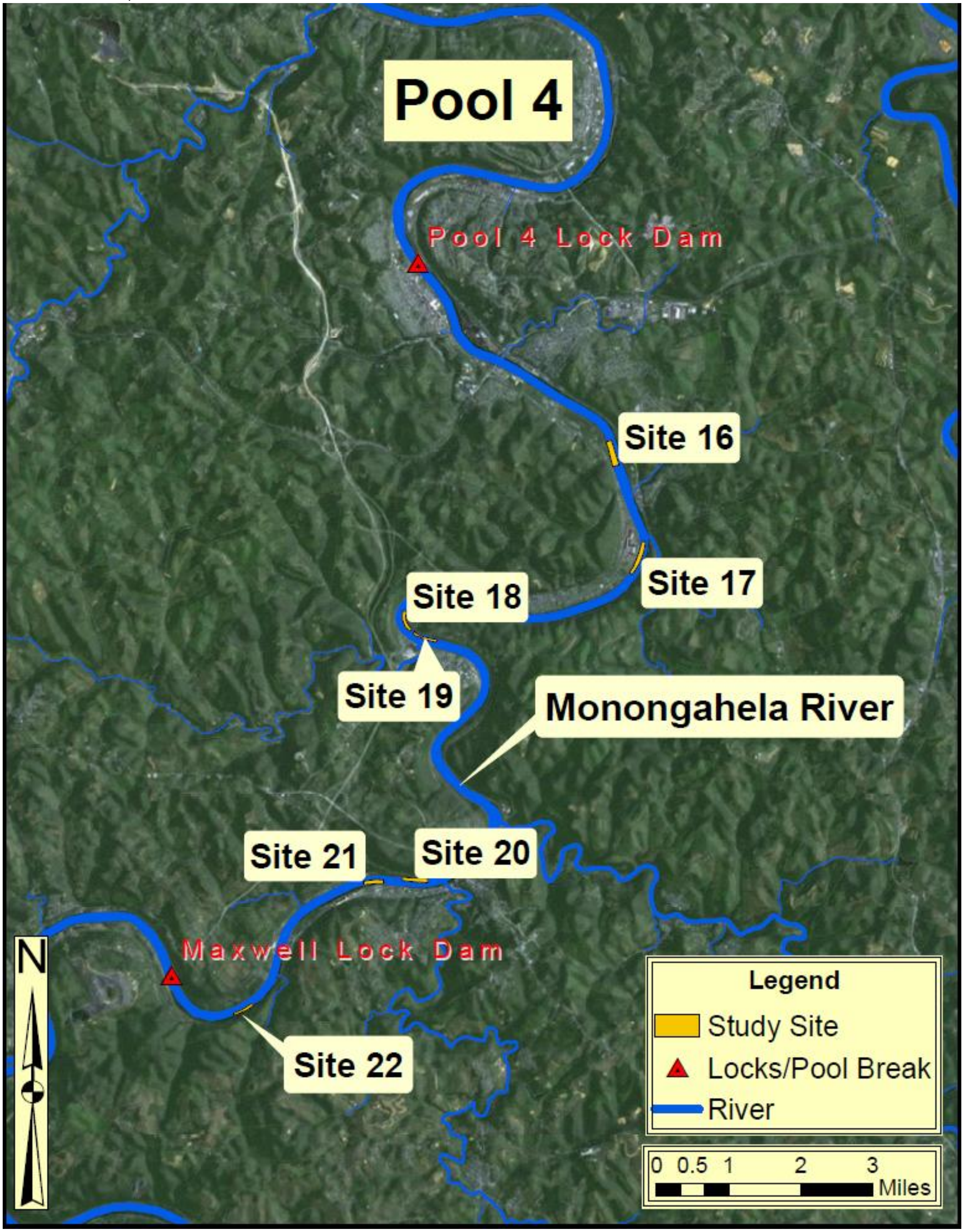


FIGURE 39. Location map of river sampling sites 23-27 in the Maxwell Pool of the Monongahela River, PA.

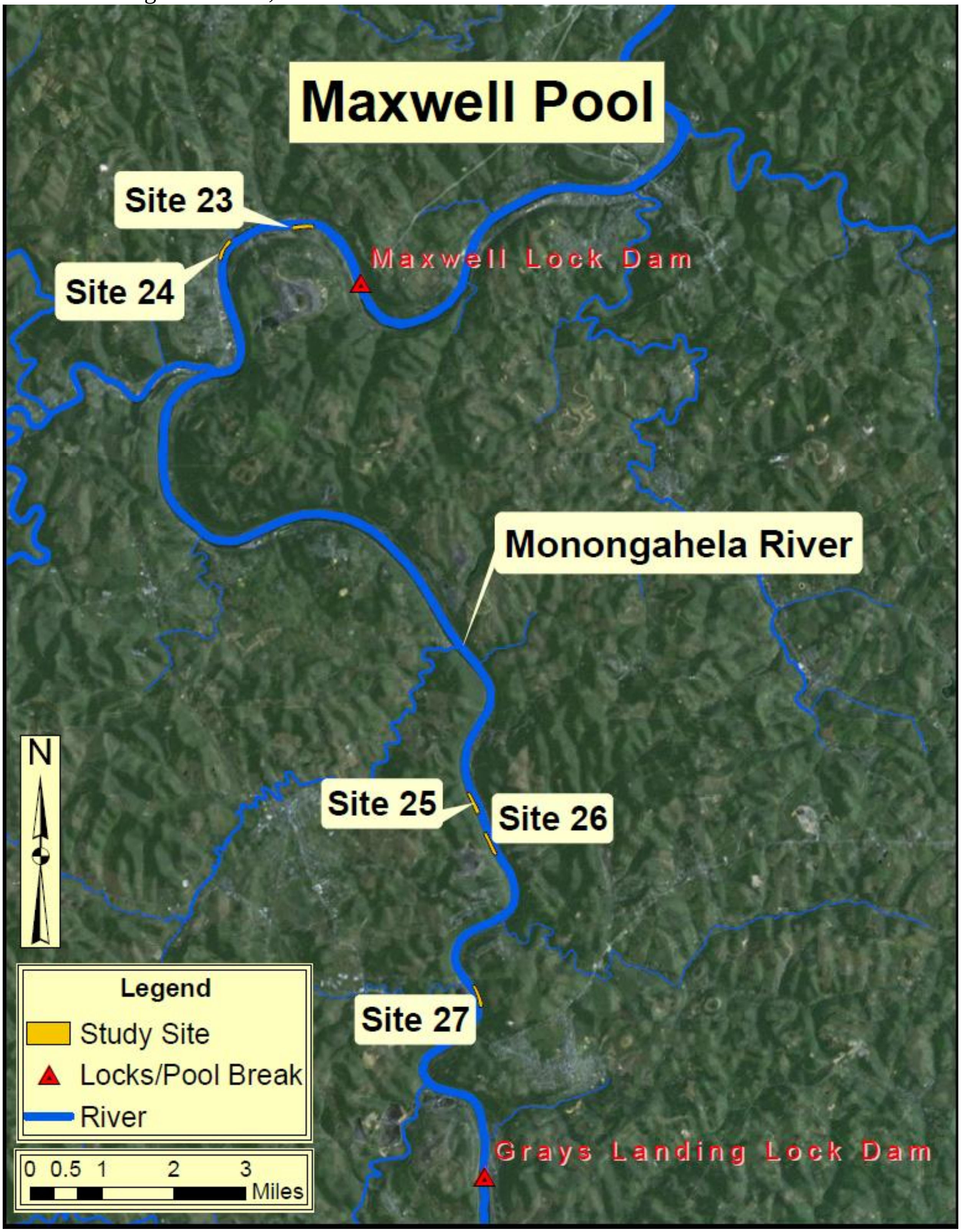


FIGURE 40. Location map of river sampling sites 28-31 in the Grays Landing Pool of the Monongahela River, PA.

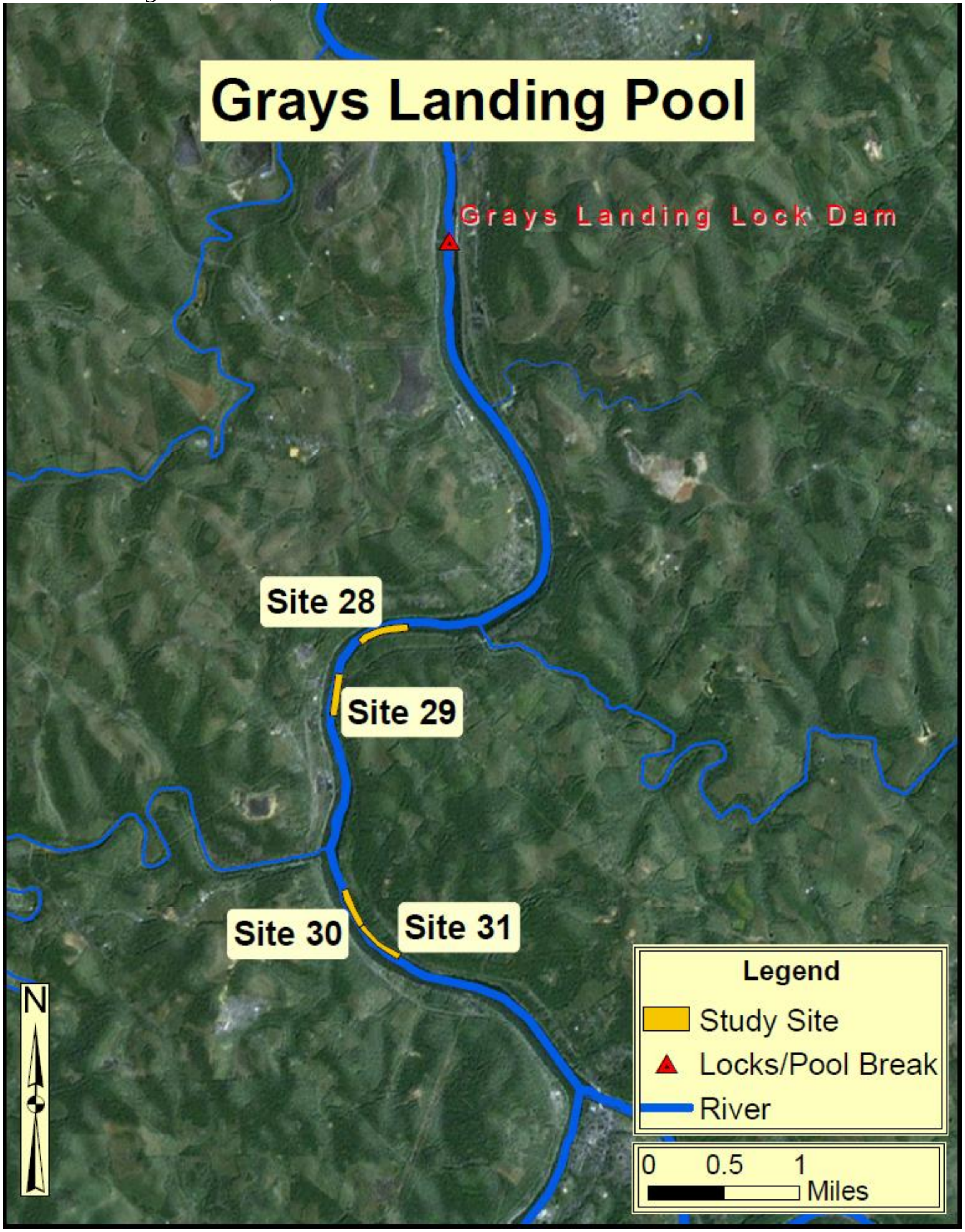


FIGURE 41. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

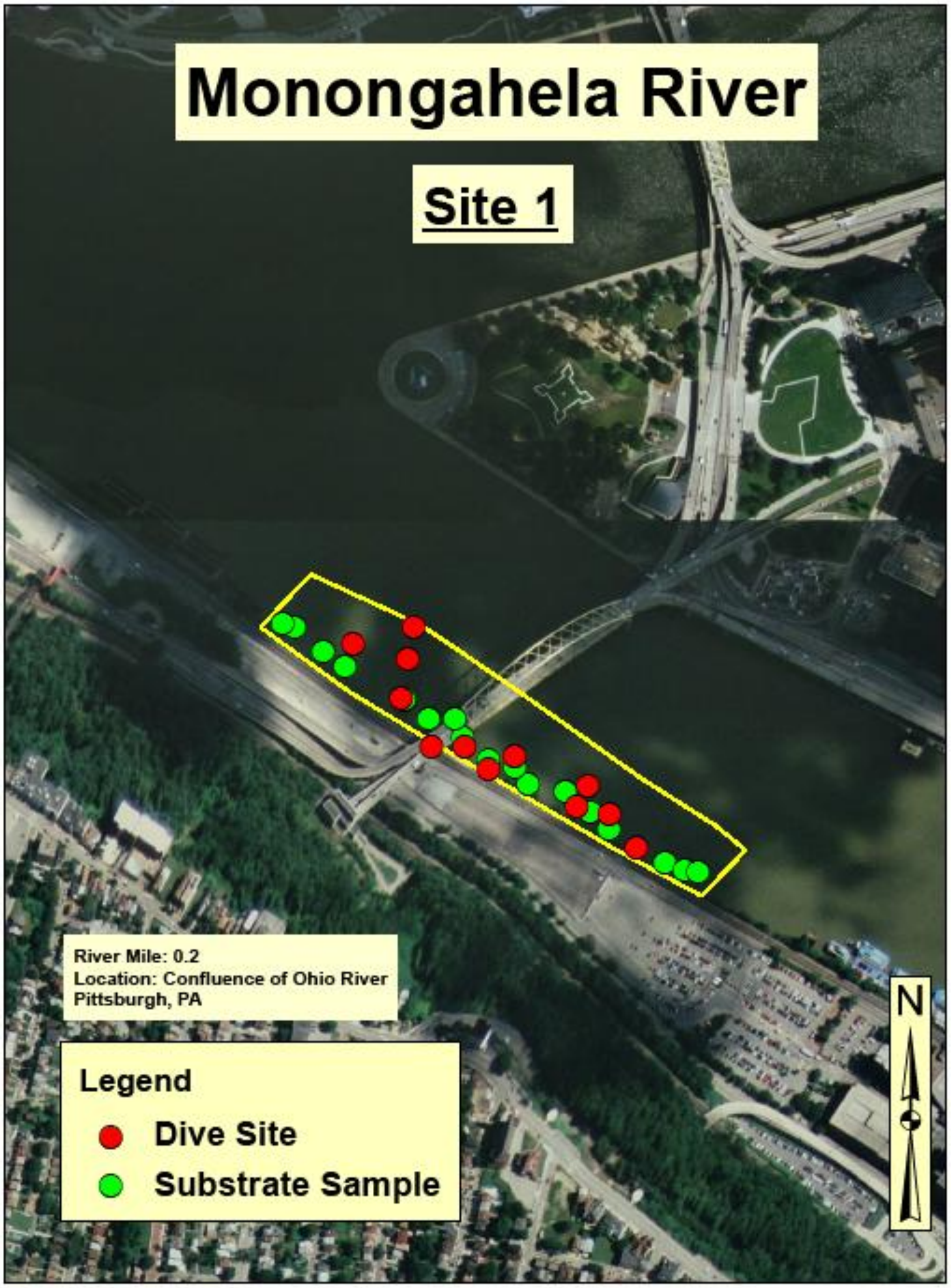


FIGURE 42. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

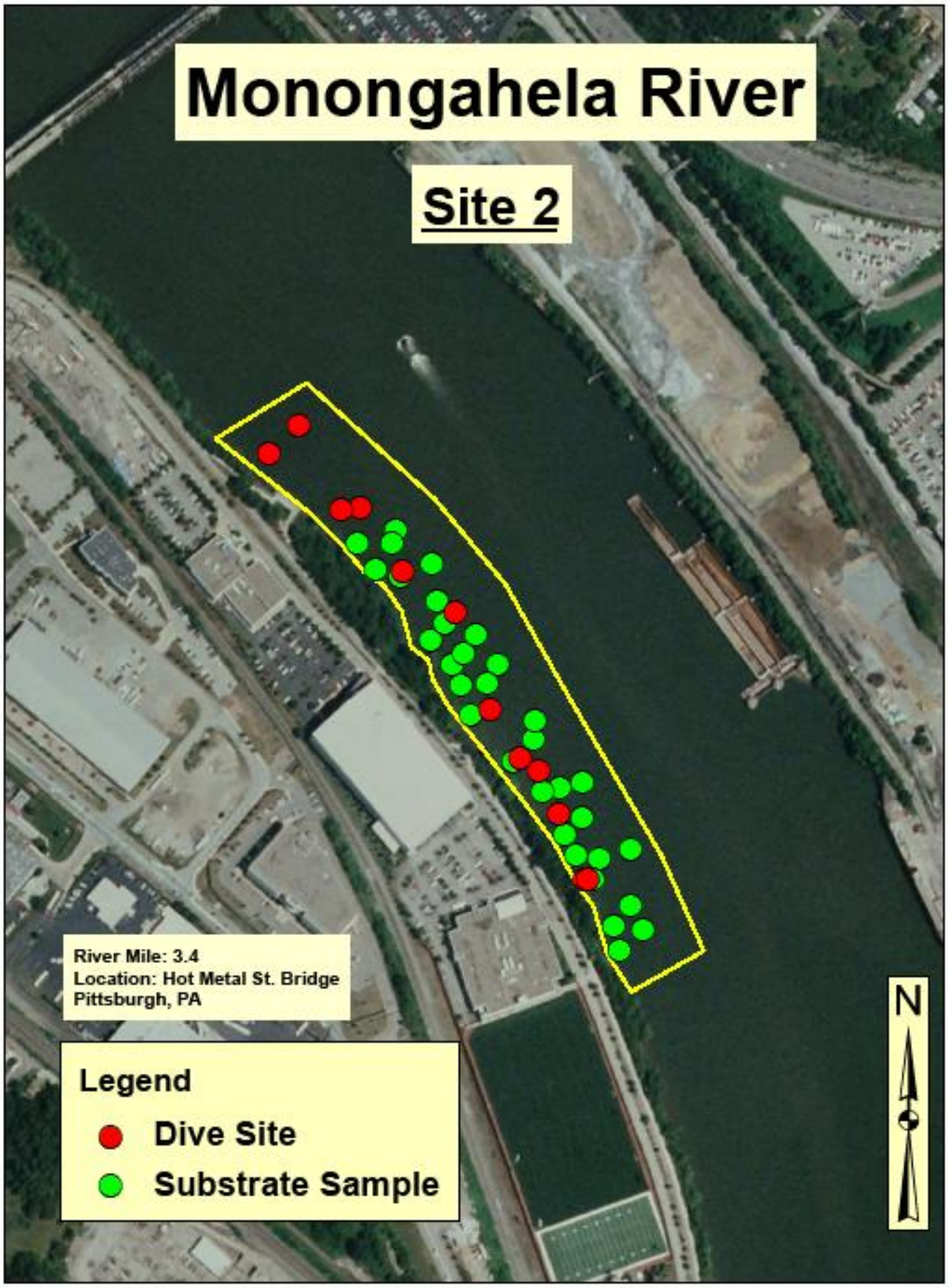


FIGURE 43. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

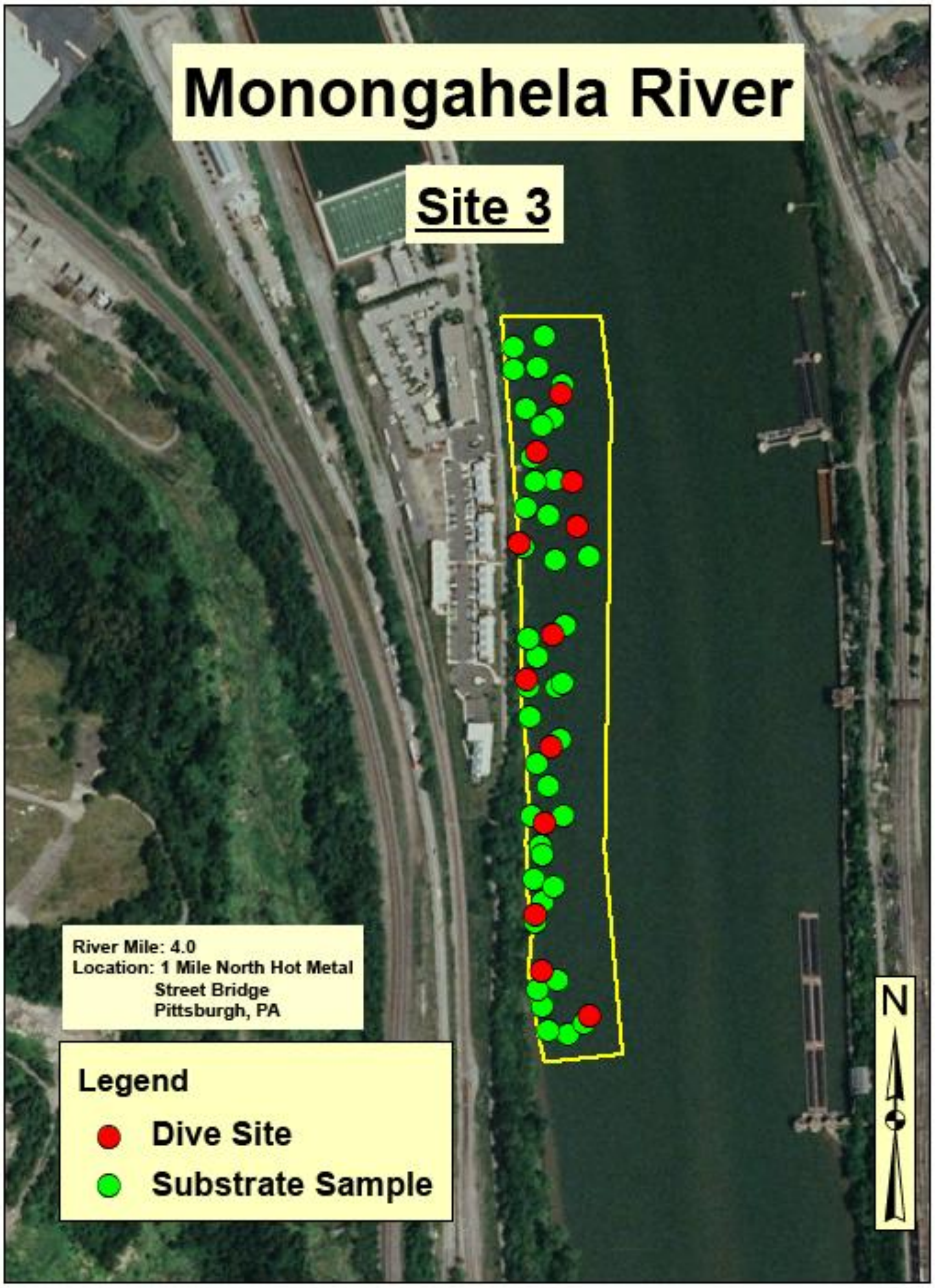


FIGURE 44. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

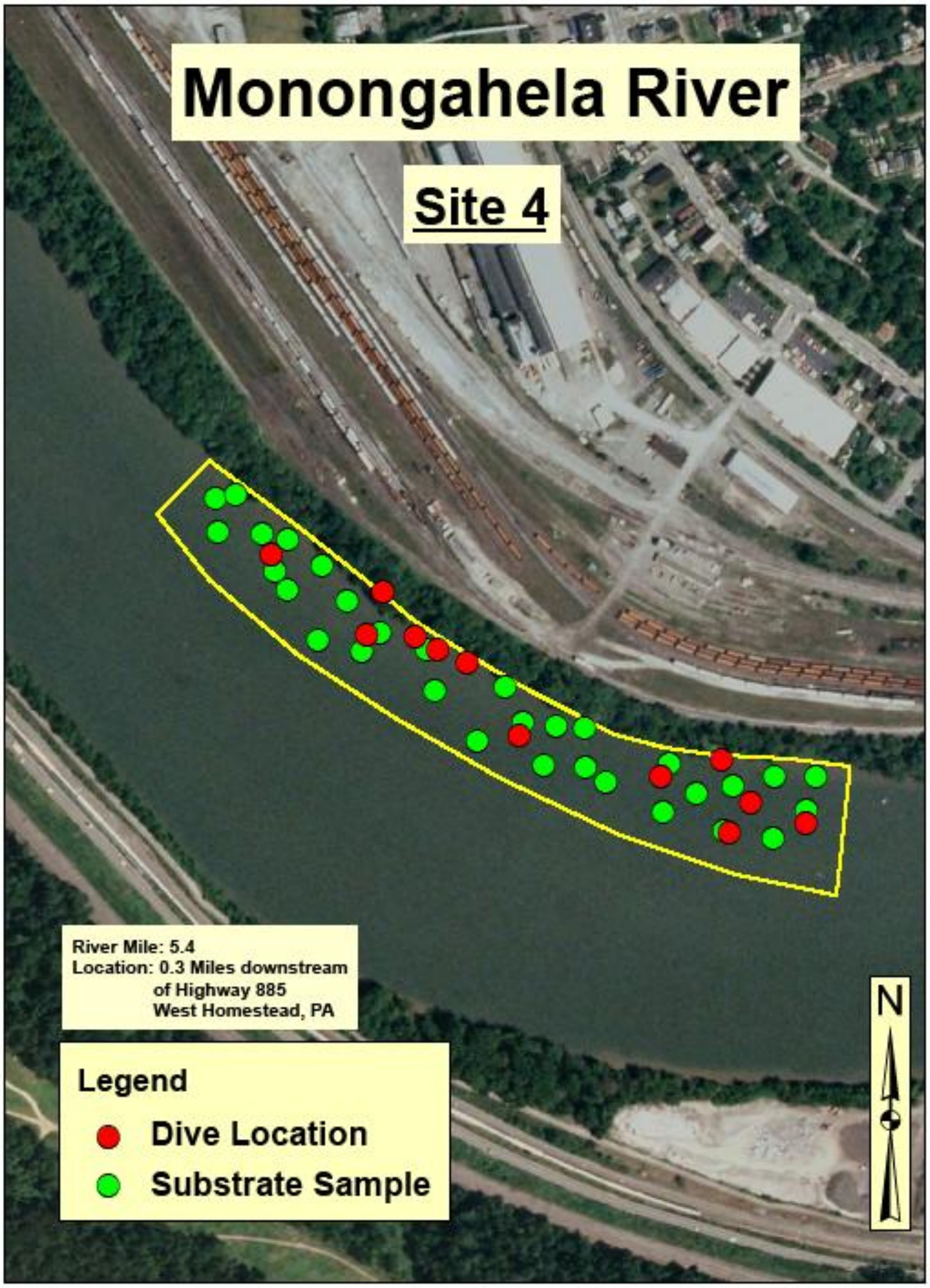


FIGURE 45. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

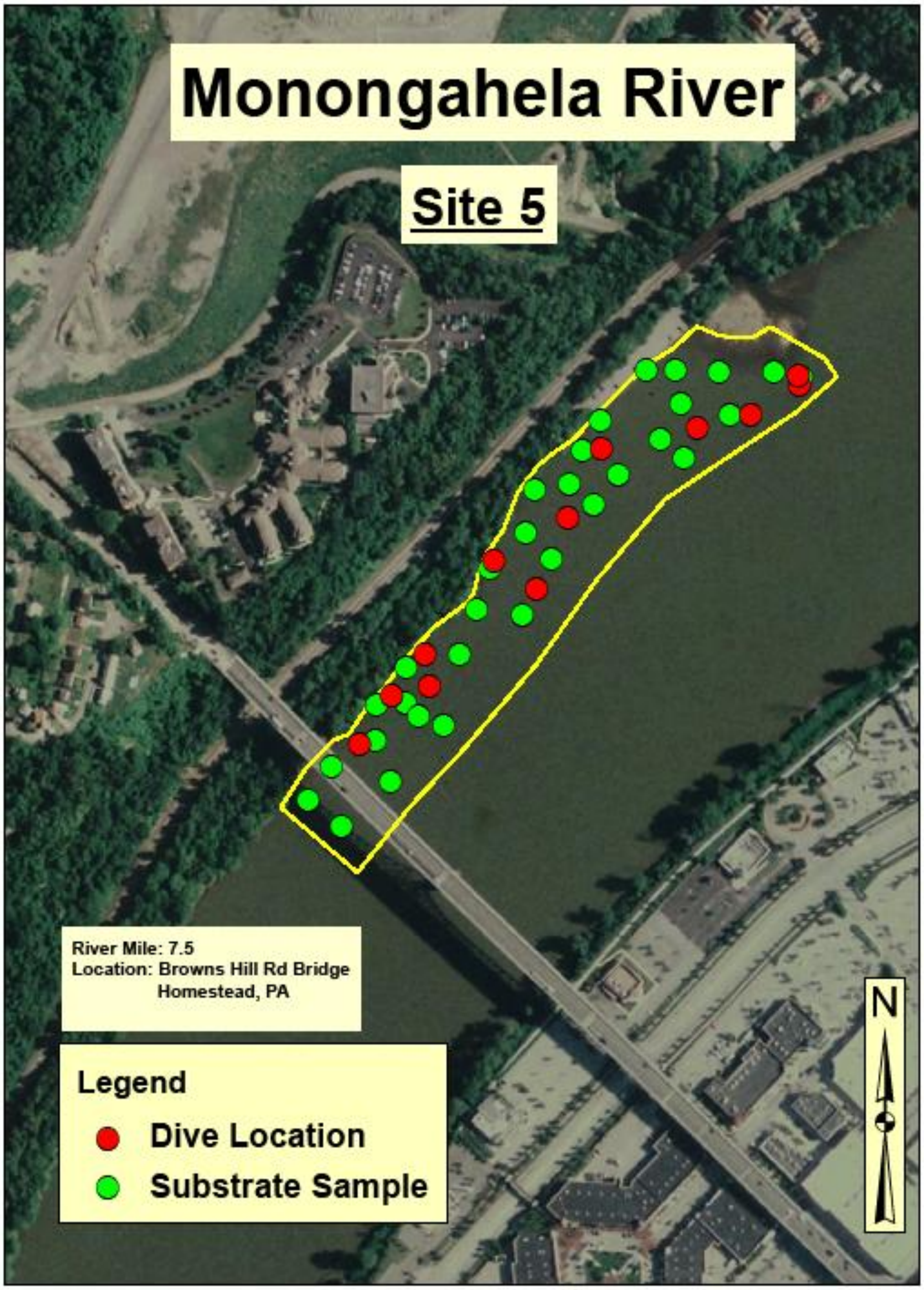


FIGURE 46. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

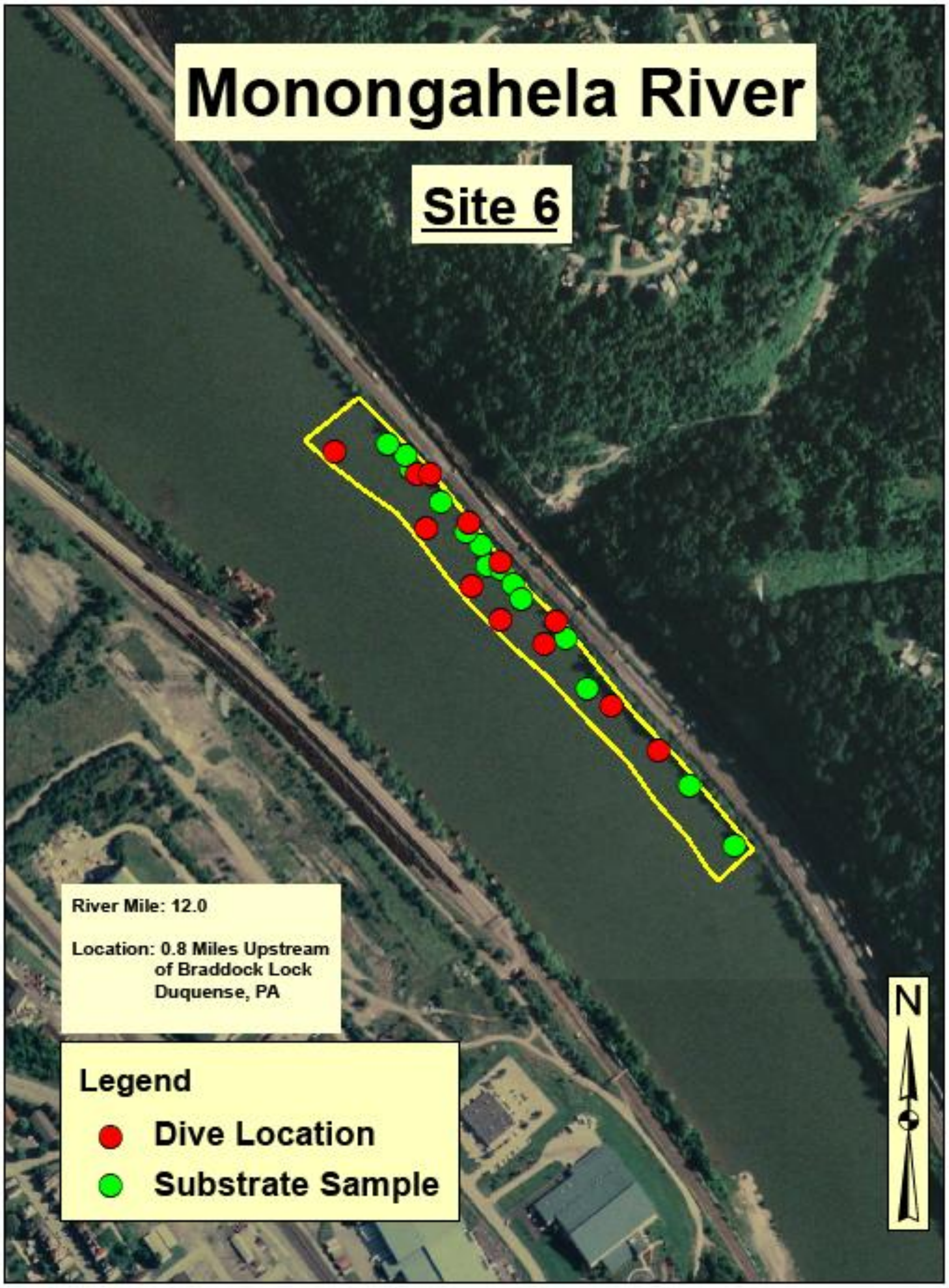


FIGURE 47. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

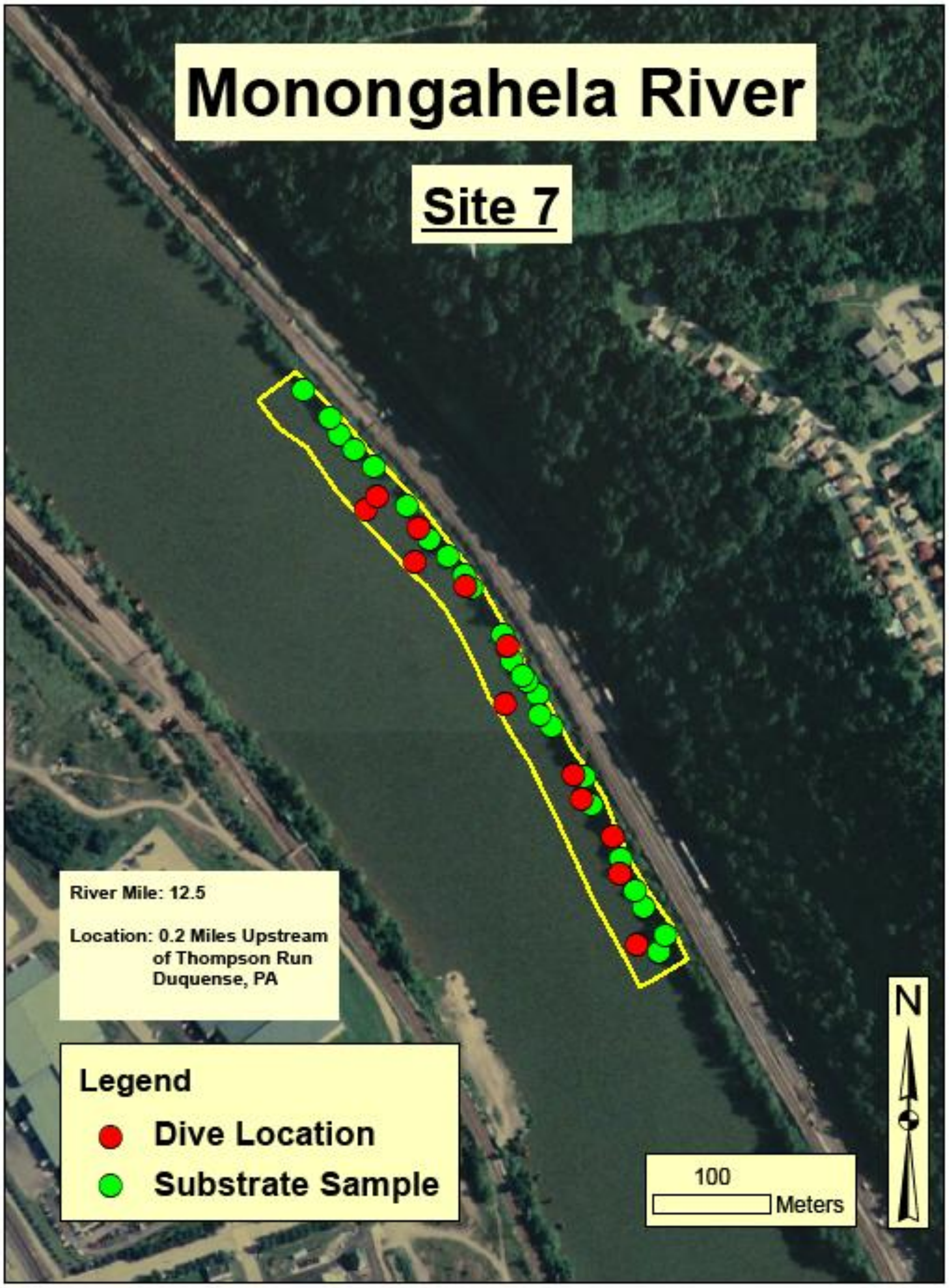


FIGURE 48. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

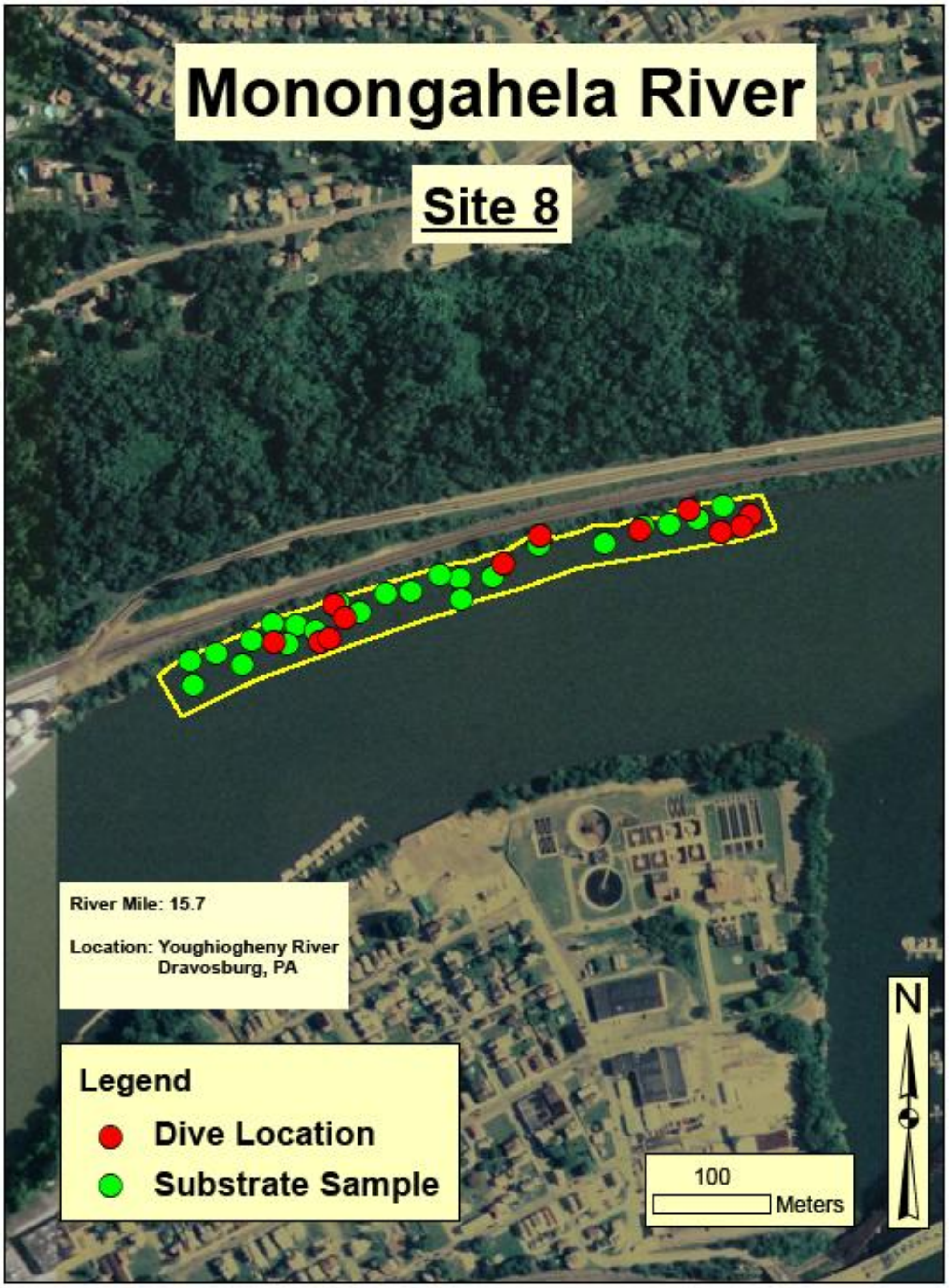


FIGURE 49. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

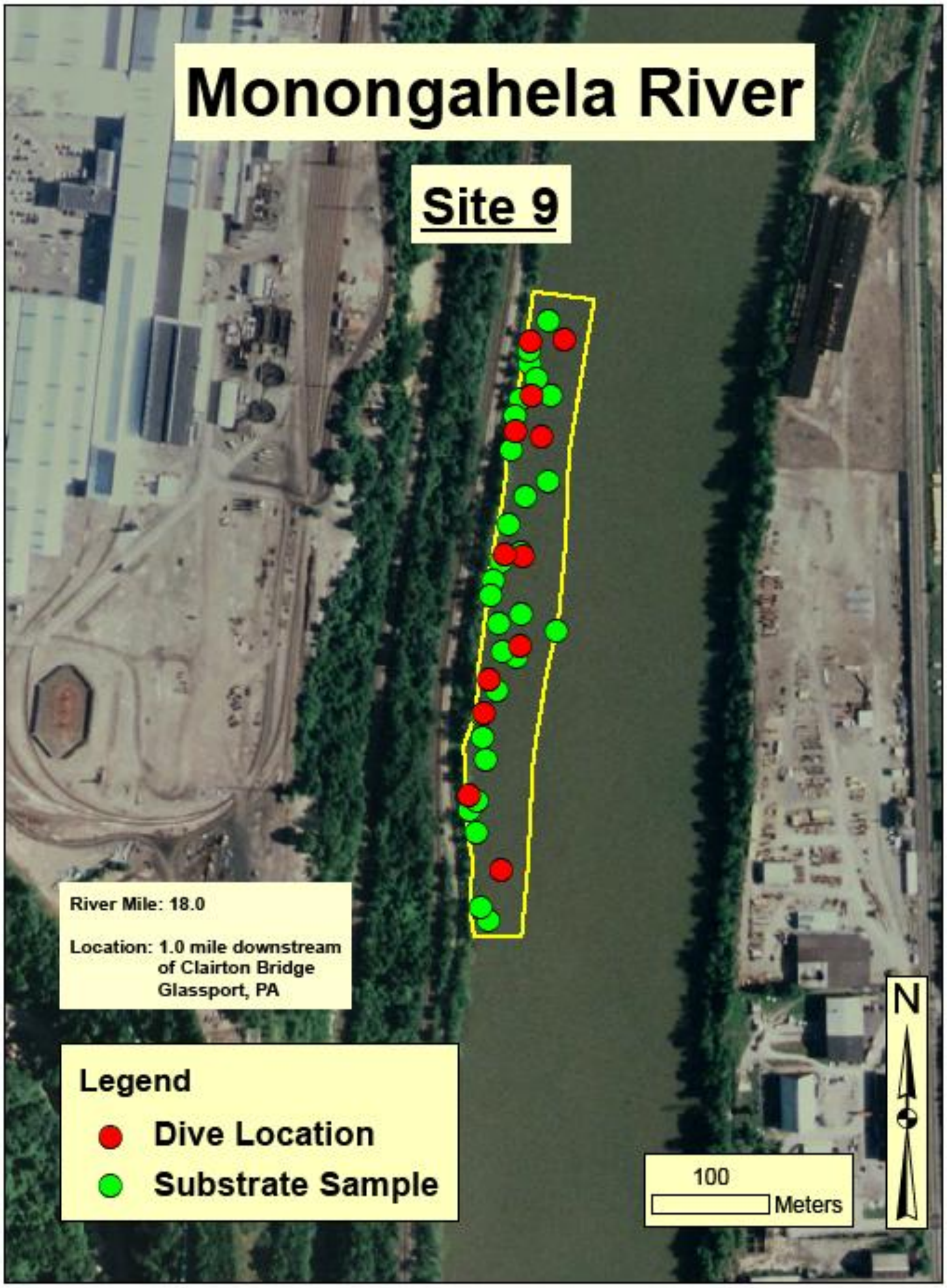


FIGURE 50. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

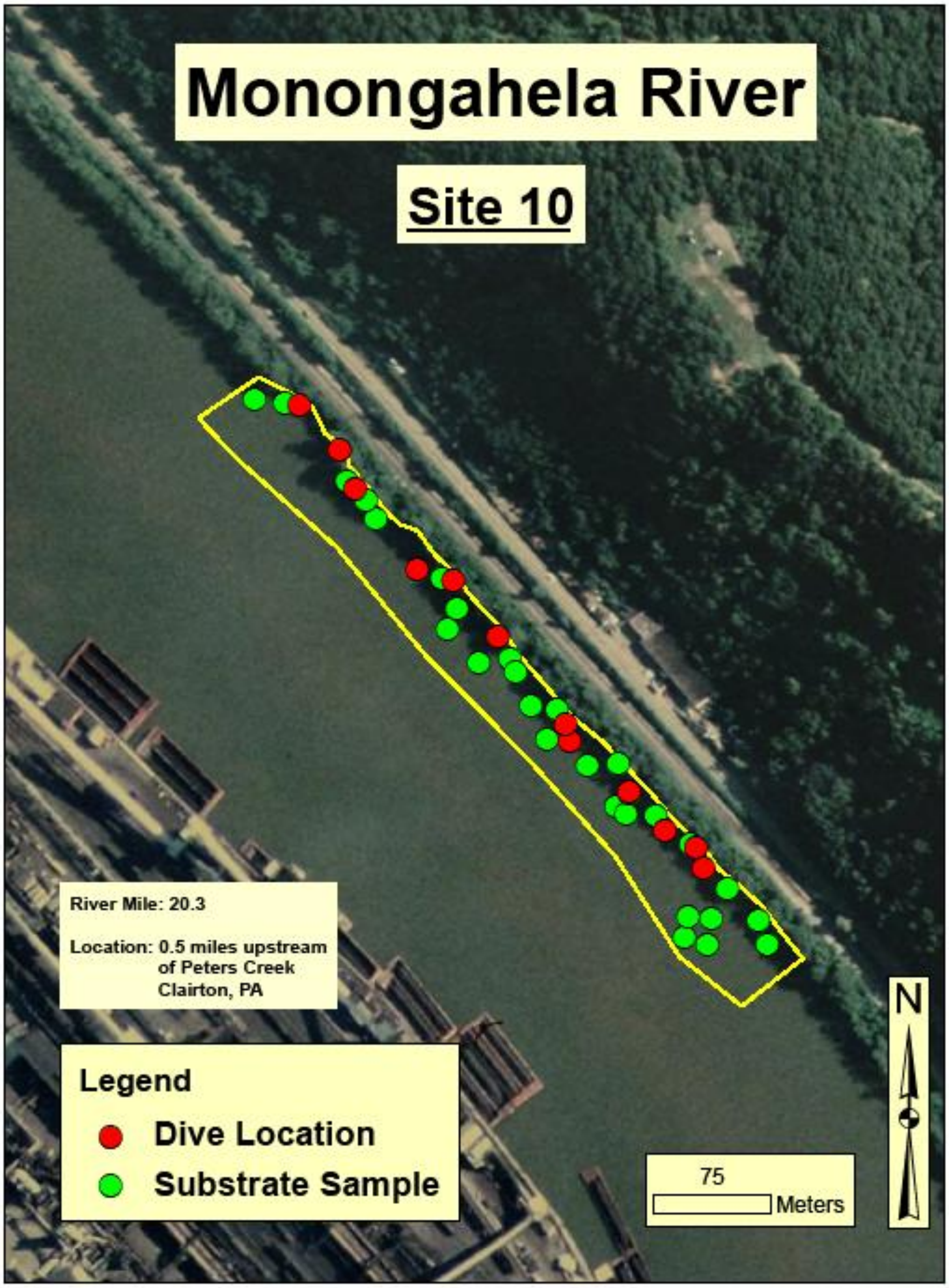


FIGURE 51. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

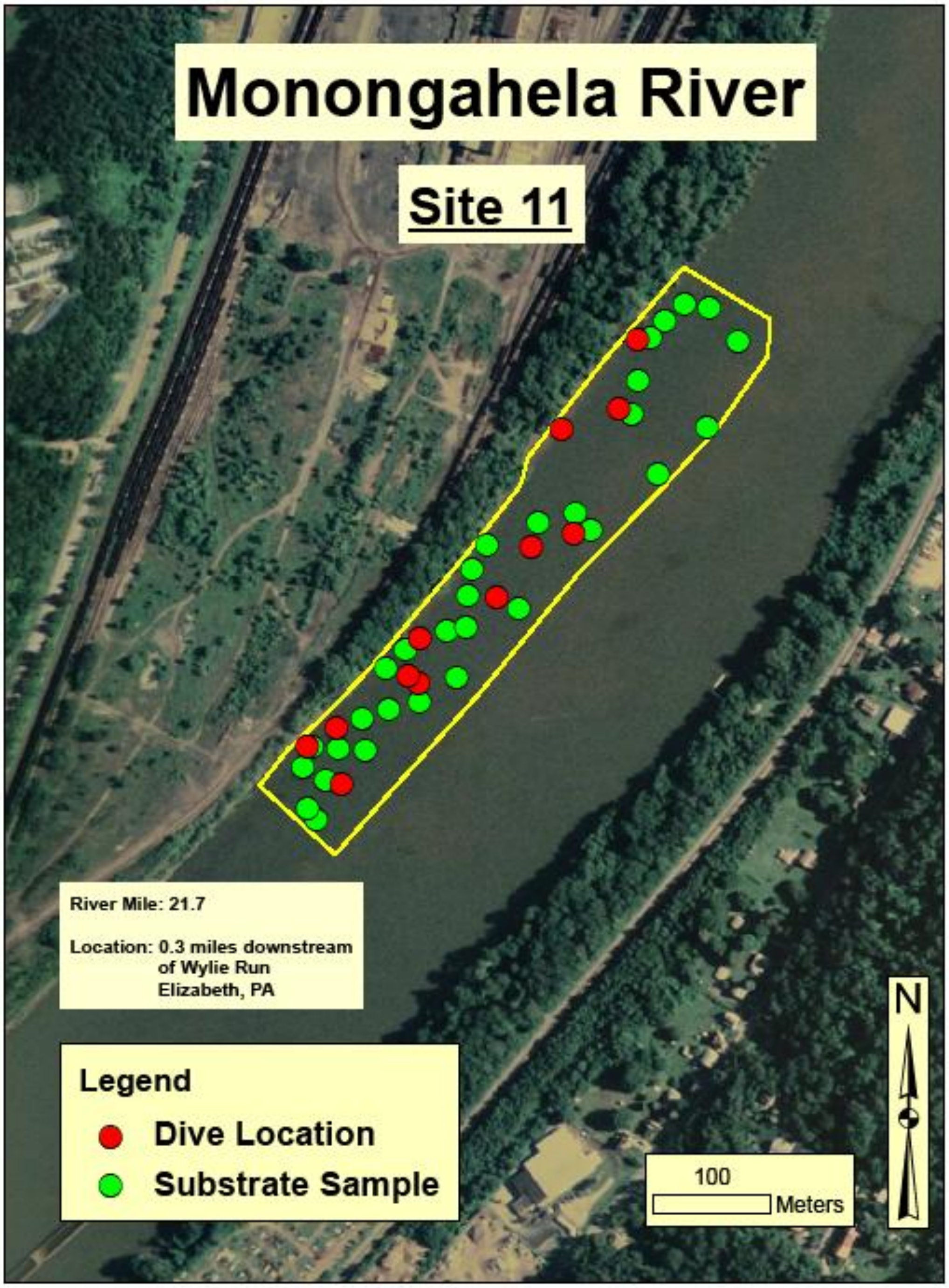
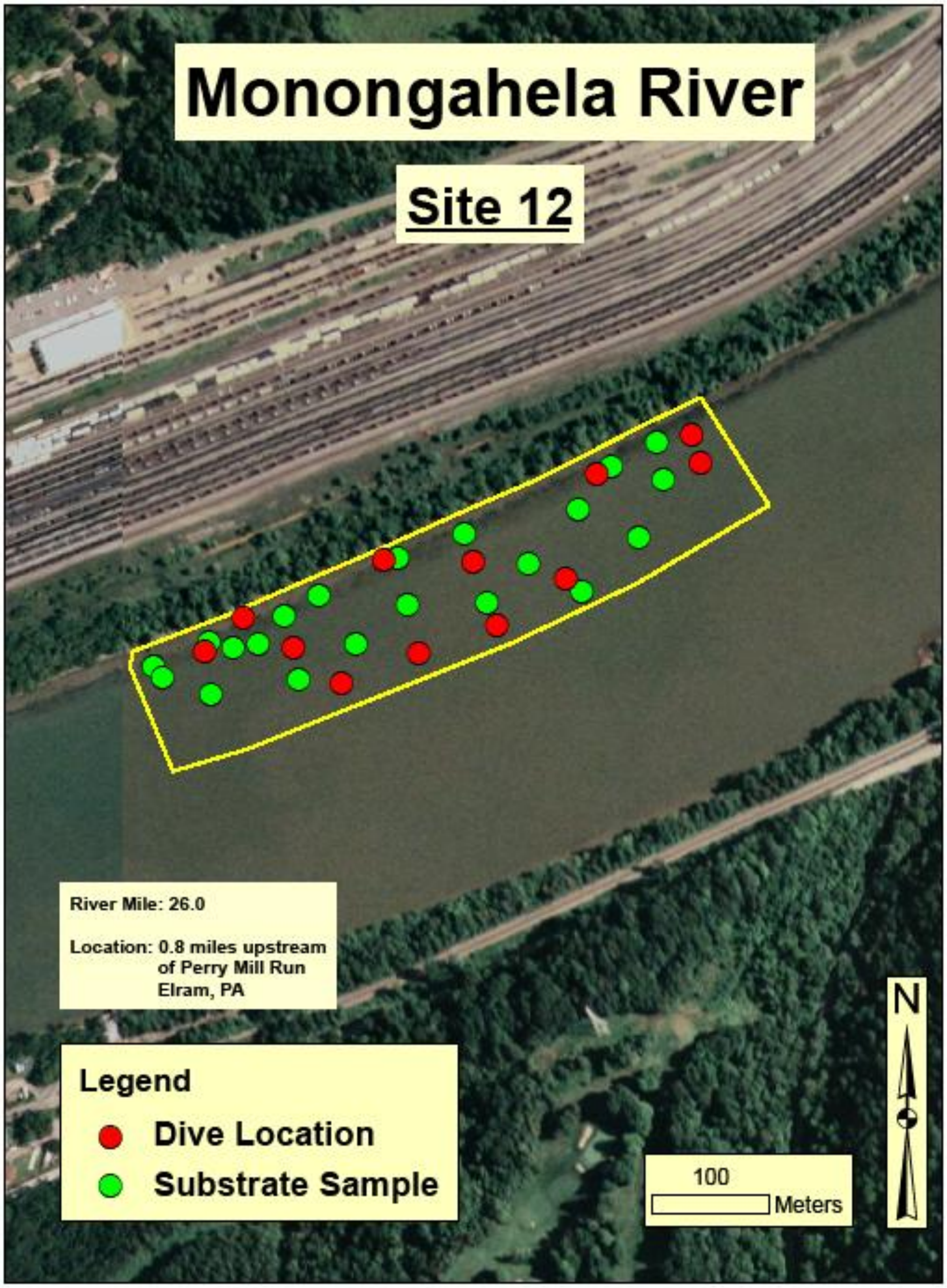


FIGURE 52. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..



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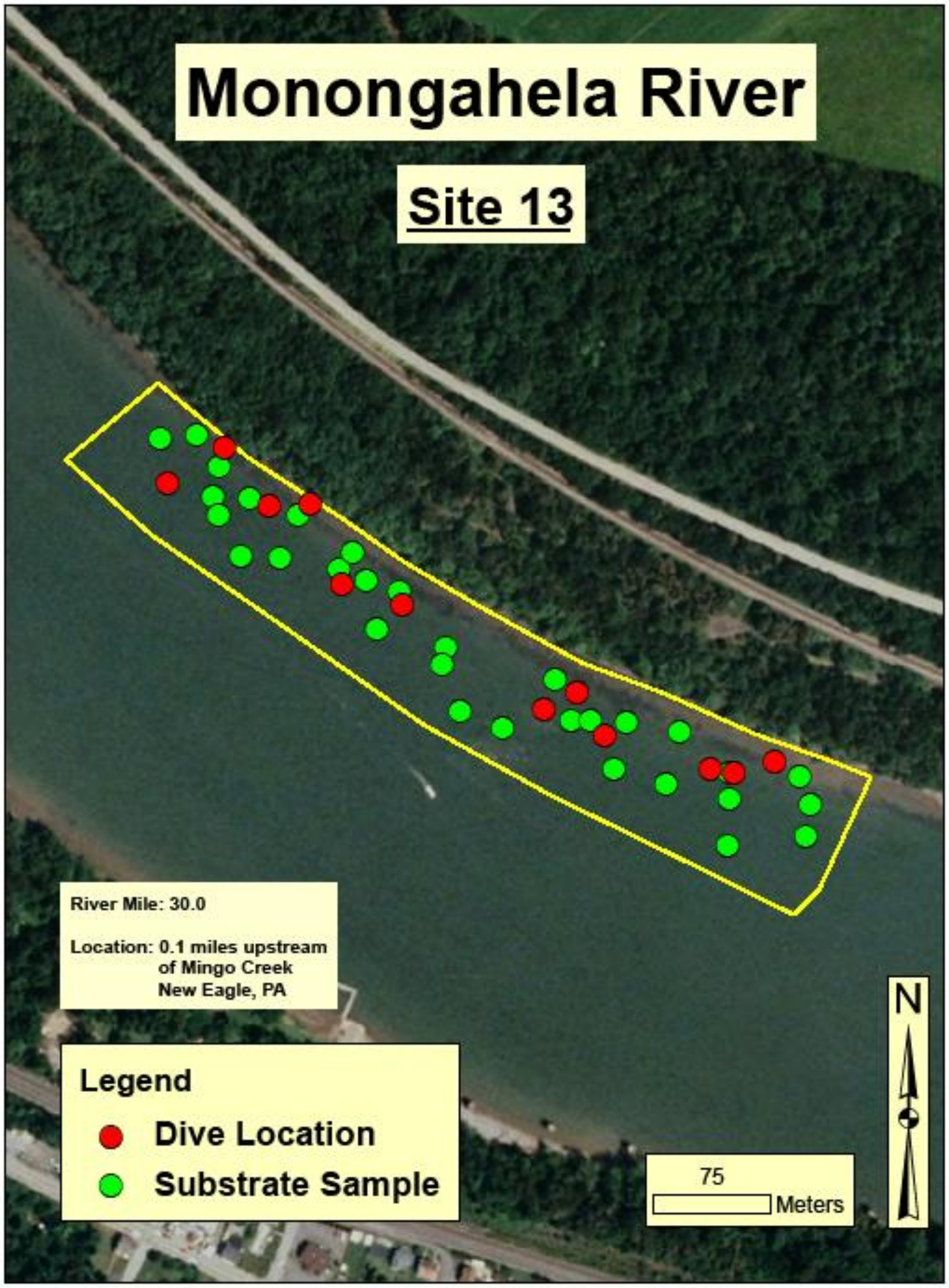


FIGURE 54. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

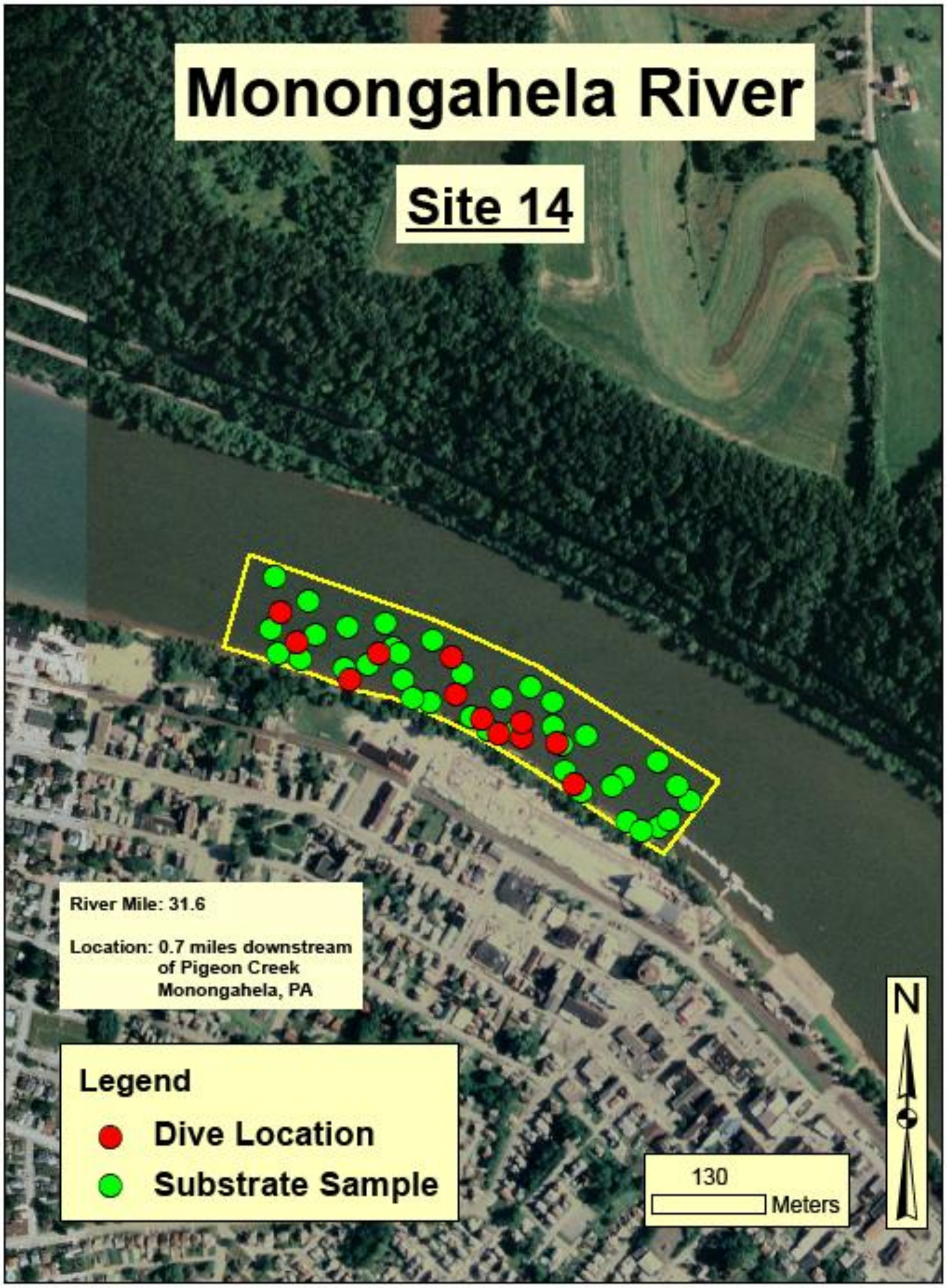


FIGURE 55. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

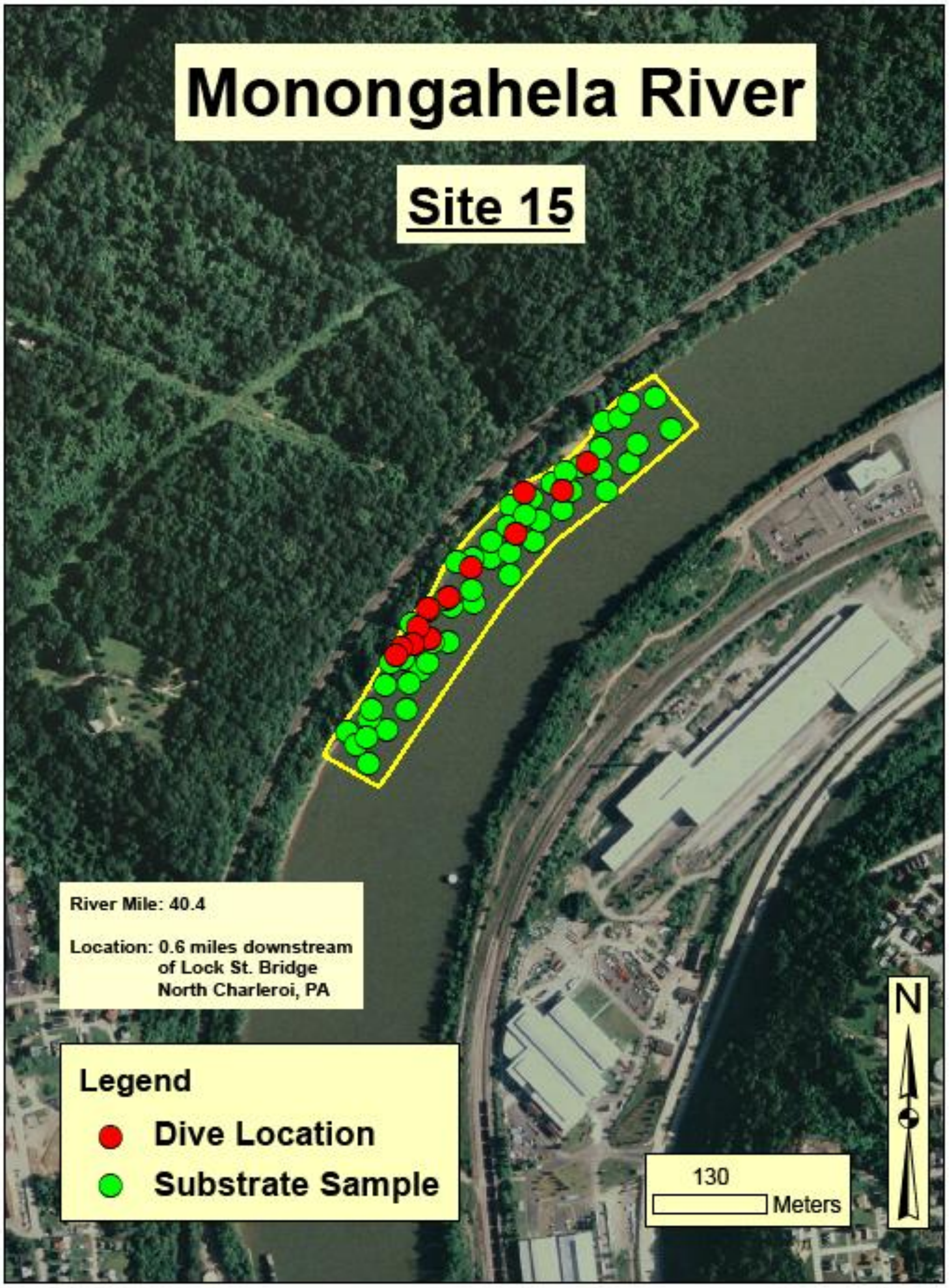
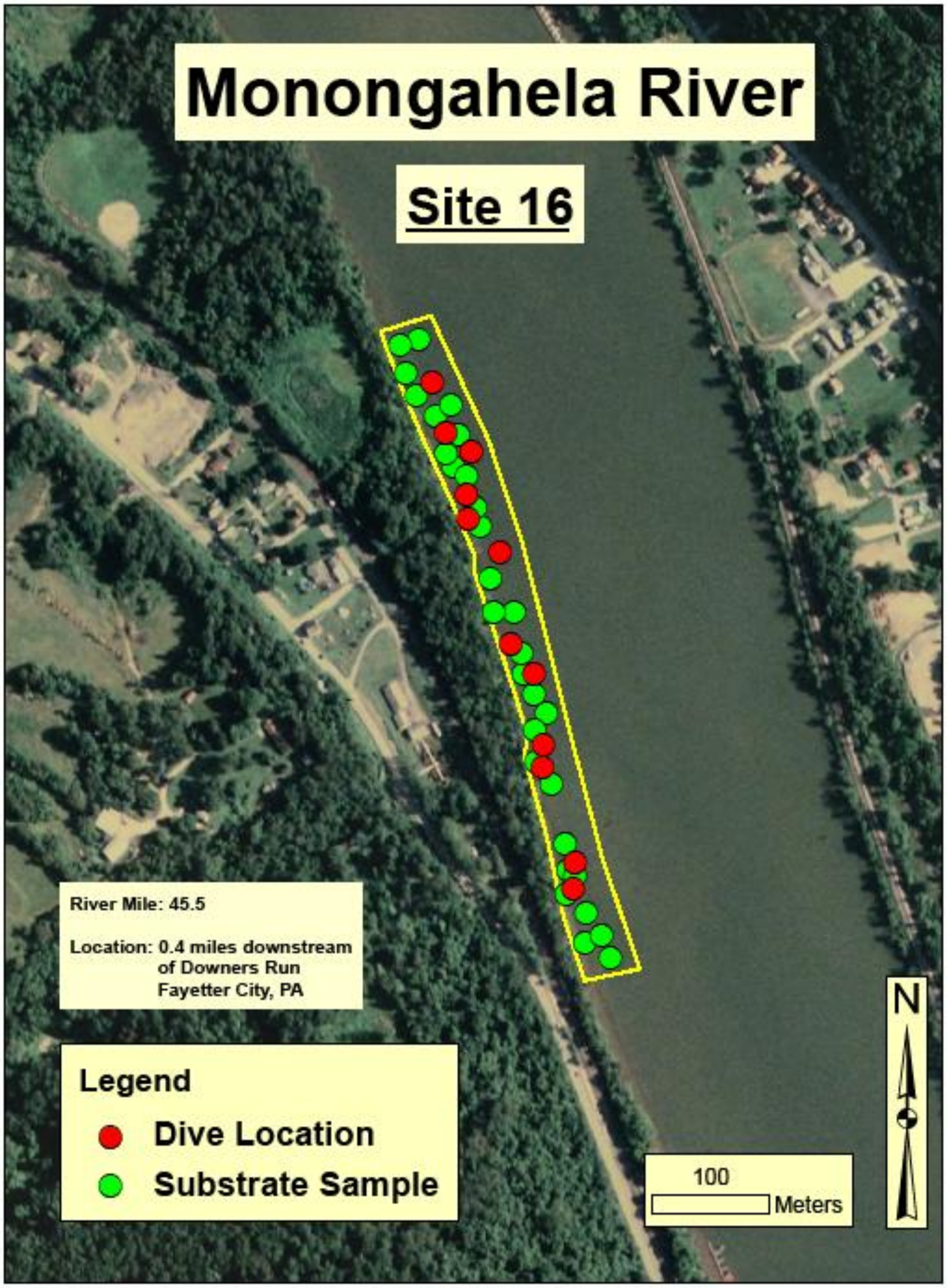


FIGURE 56. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..



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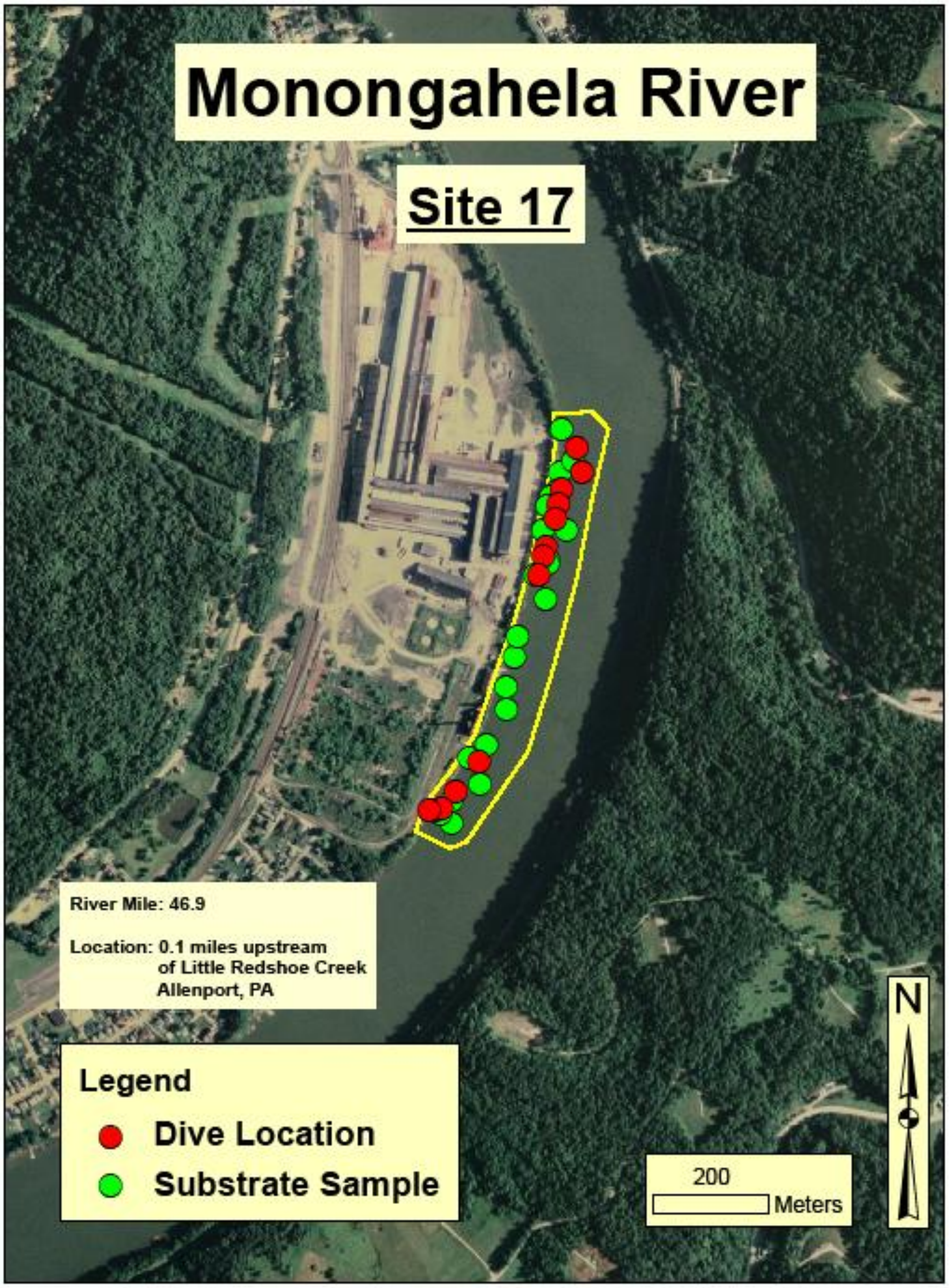


FIGURE 58. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

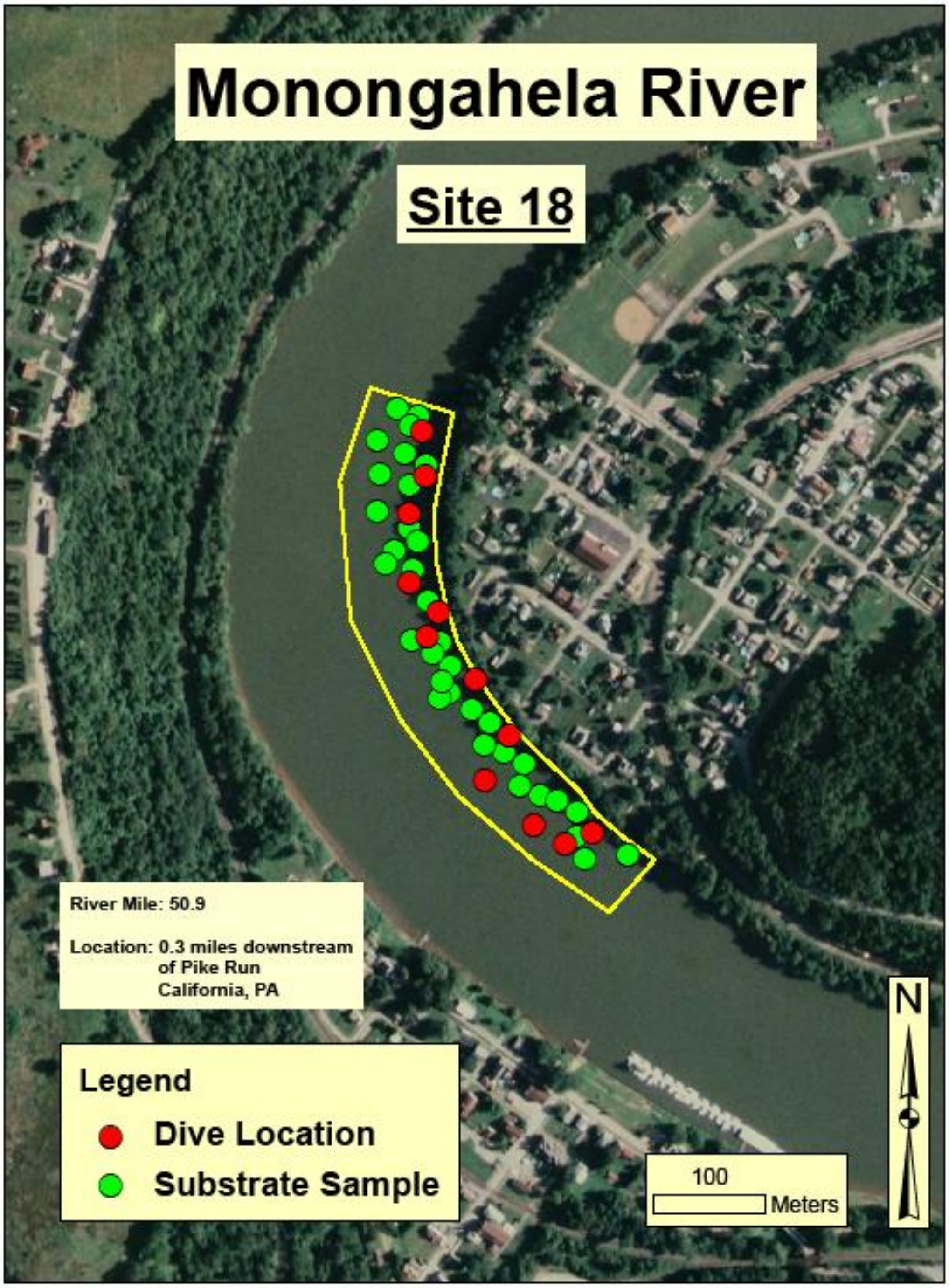


FIGURE 59. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

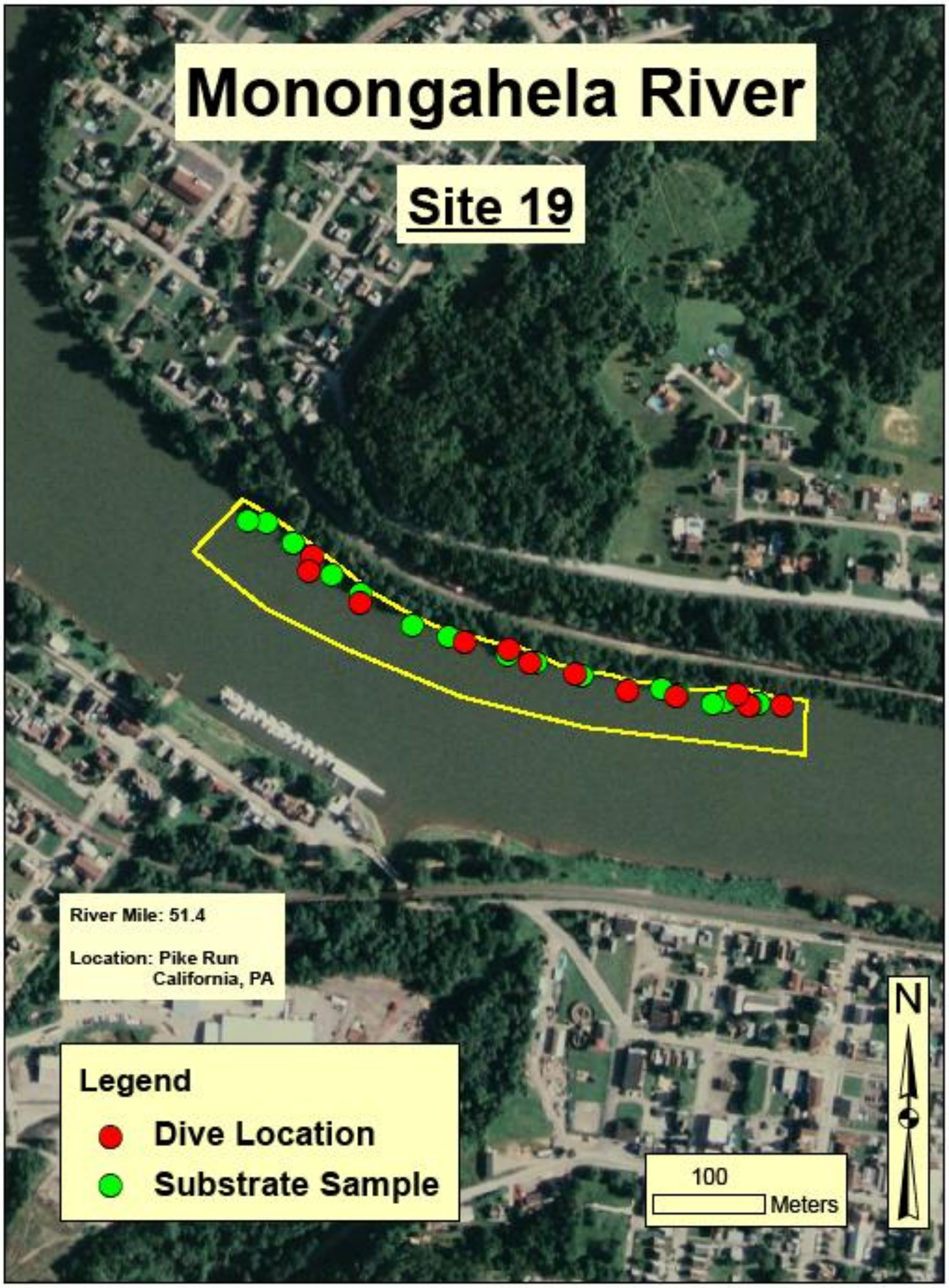


FIGURE 60. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

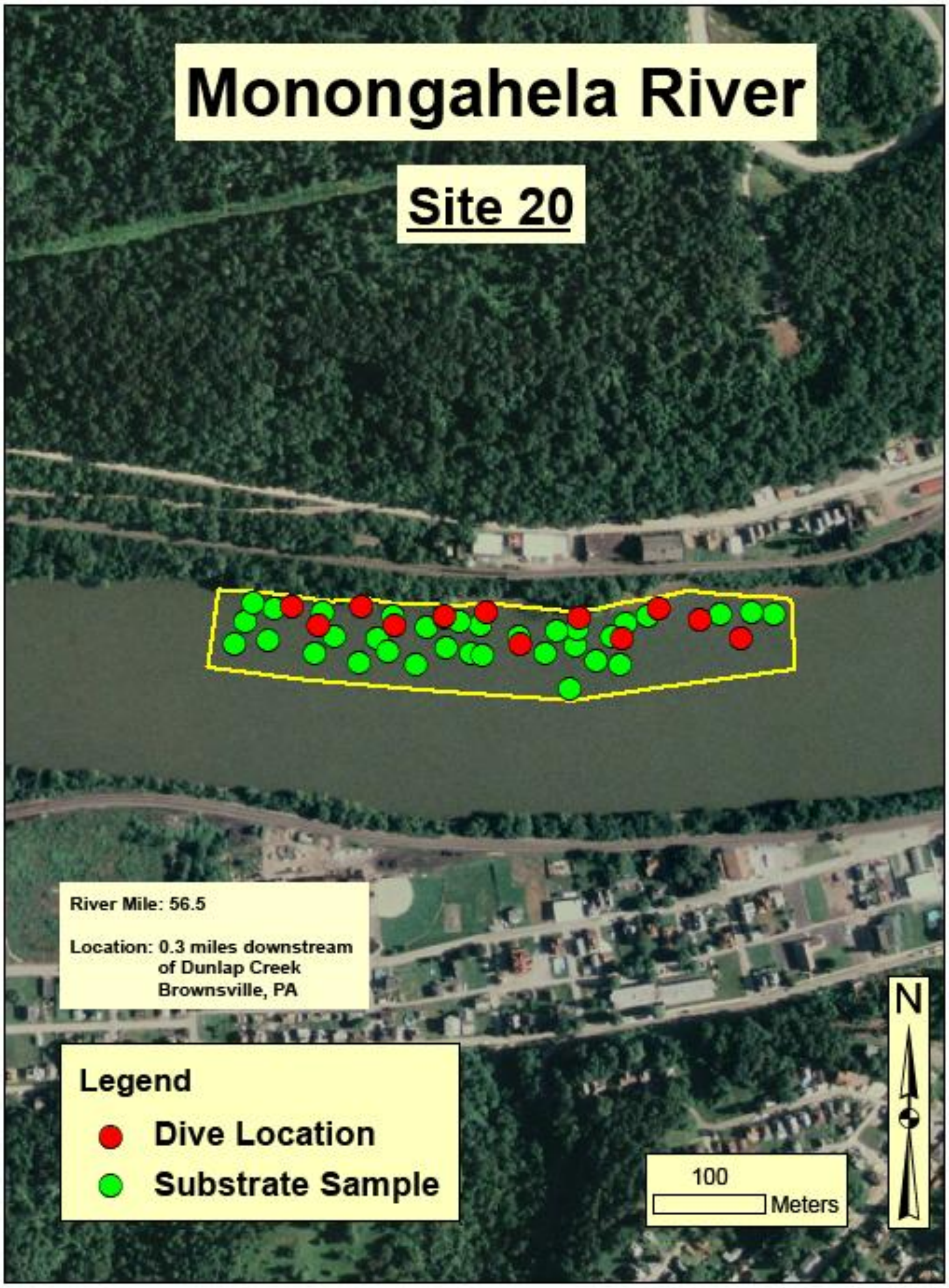


FIGURE 61. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

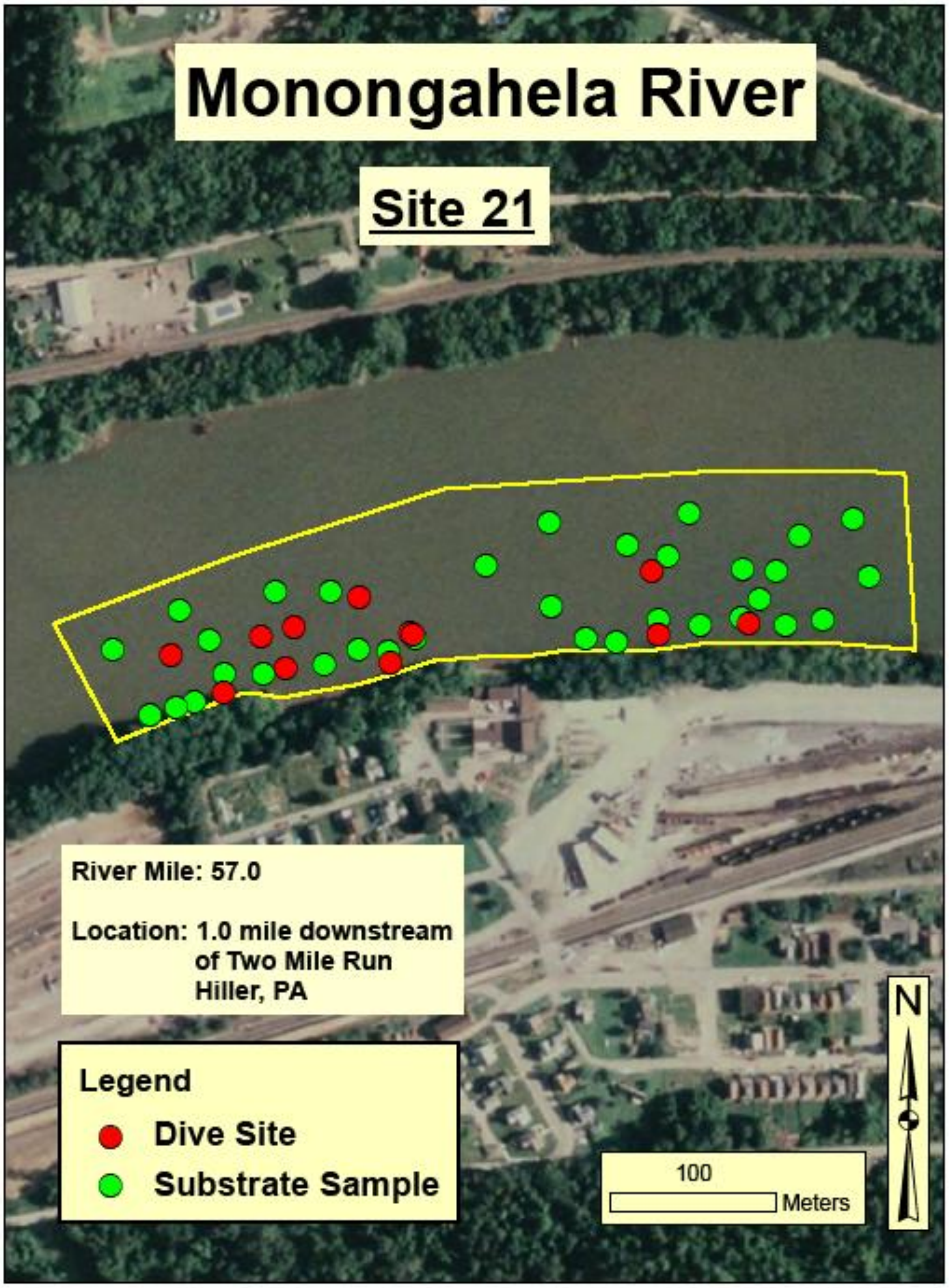


FIGURE 62. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

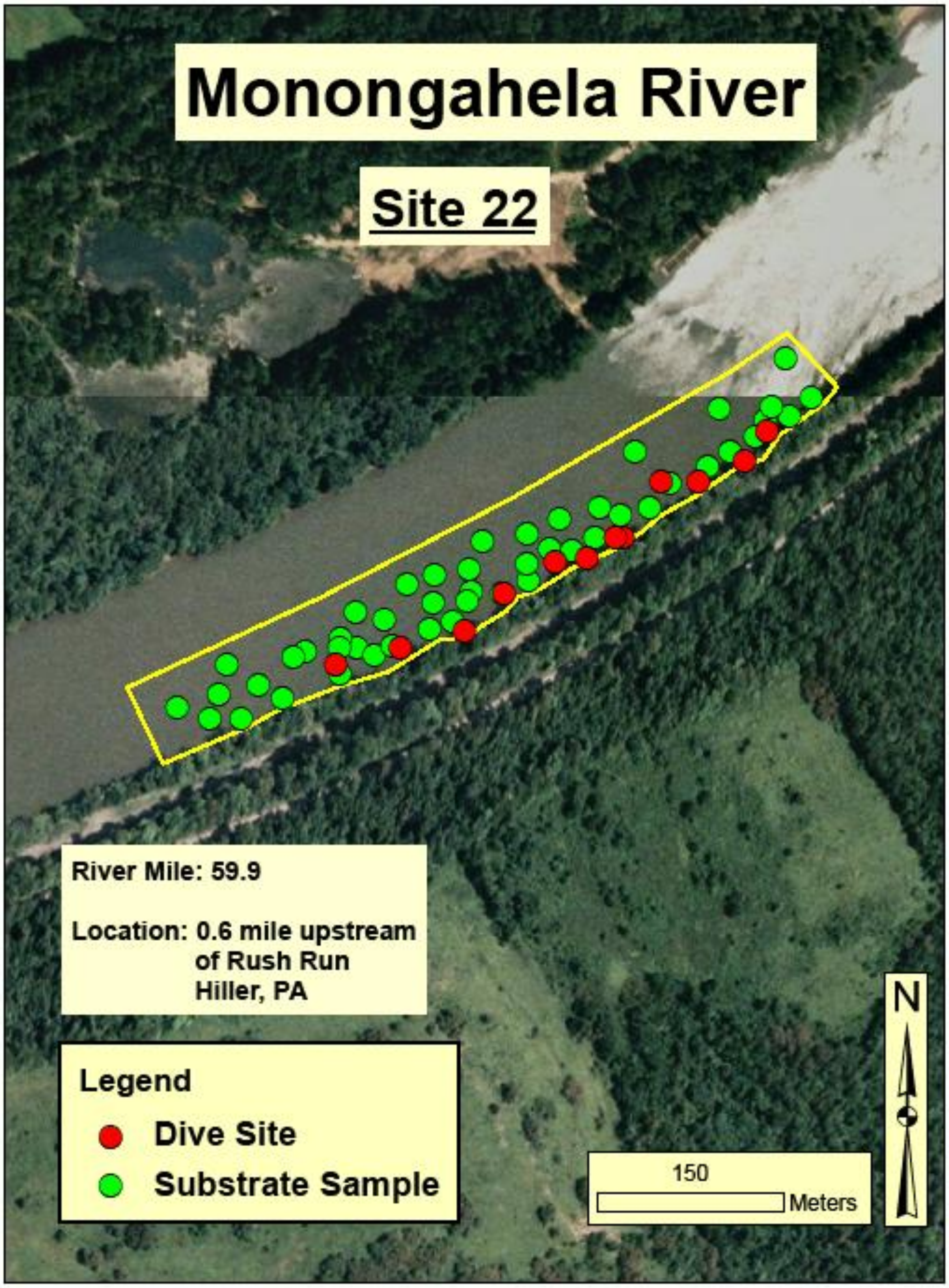


FIGURE 63. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

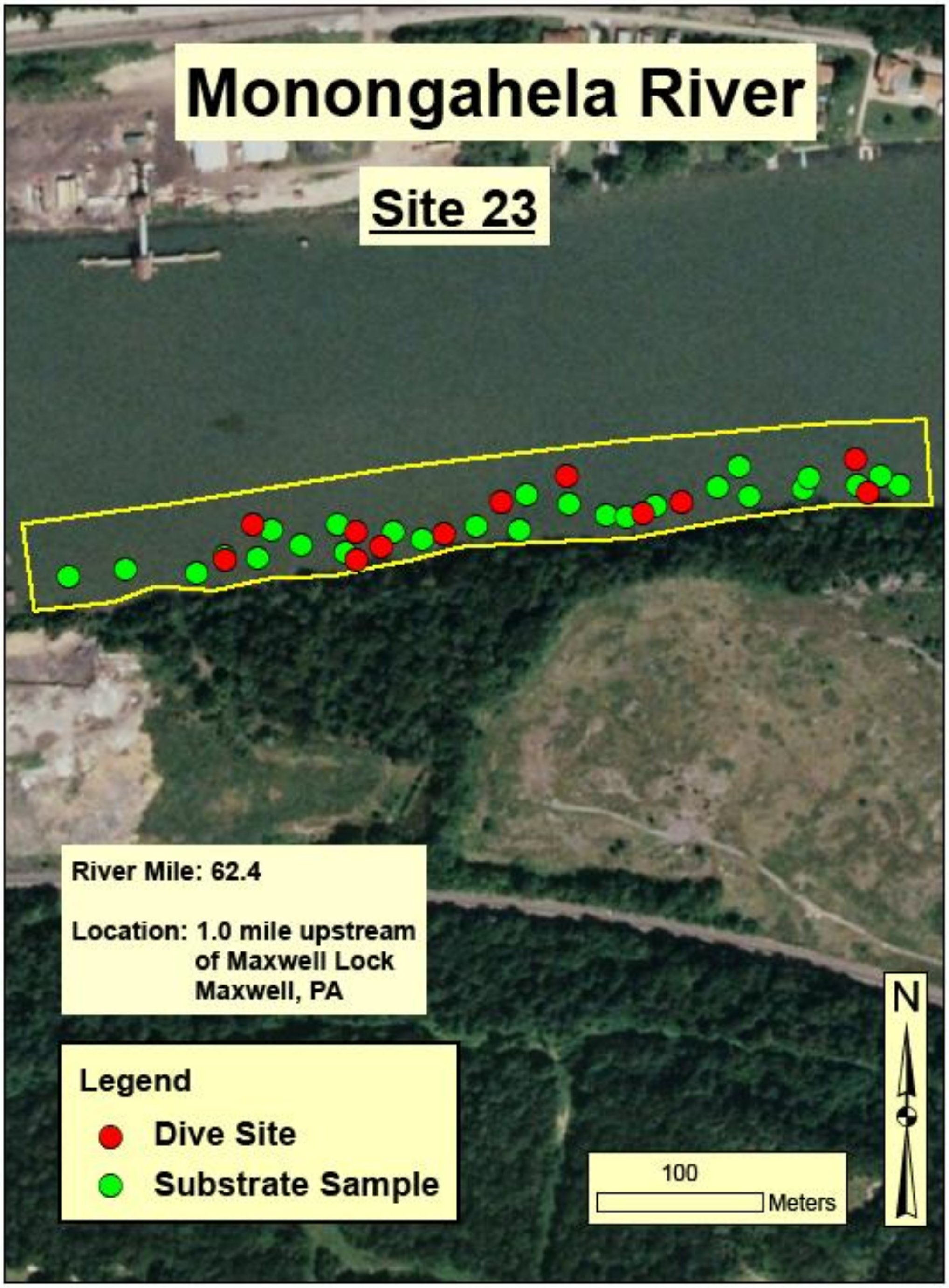


FIGURE 64. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

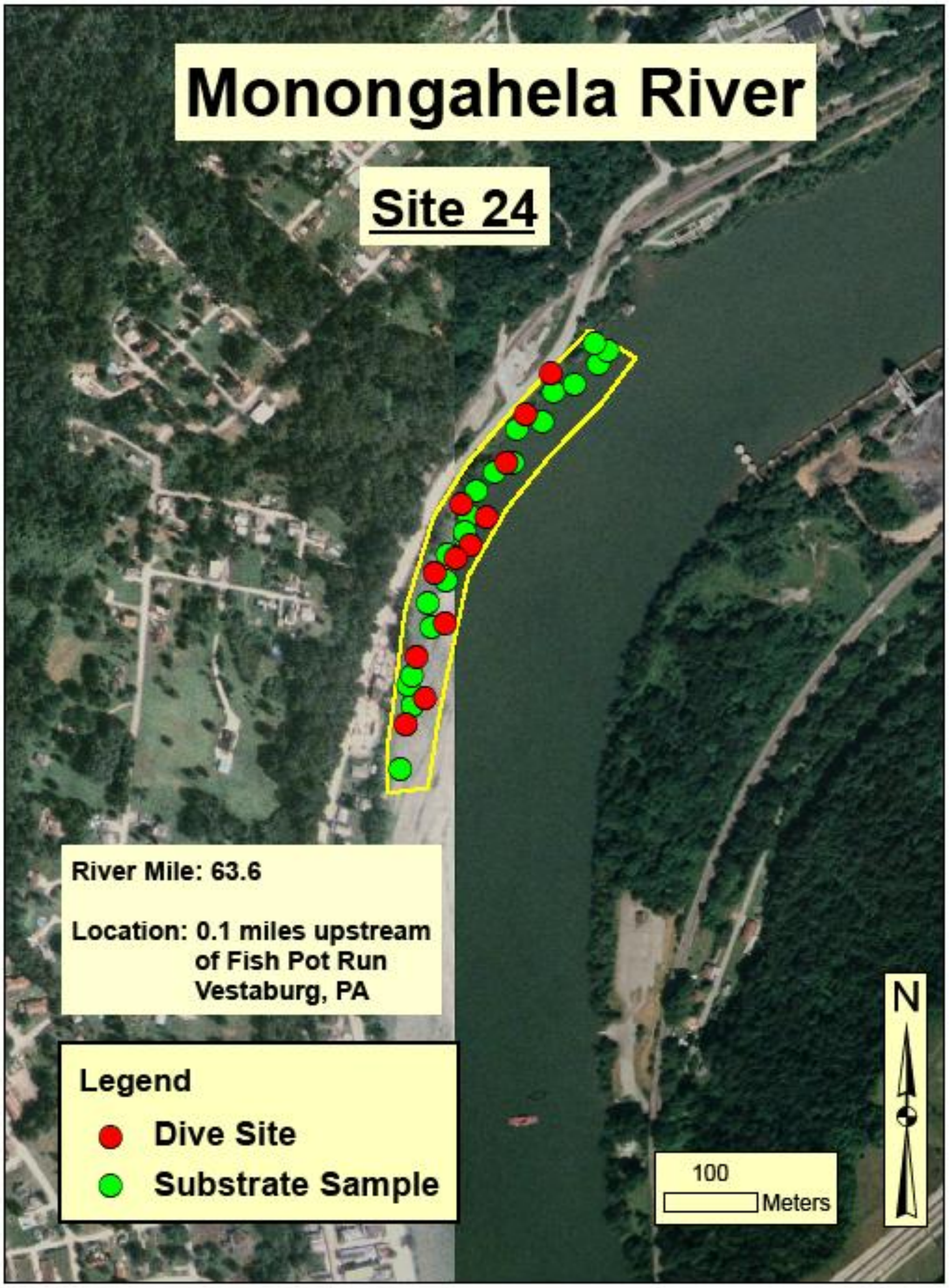


FIGURE 65. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

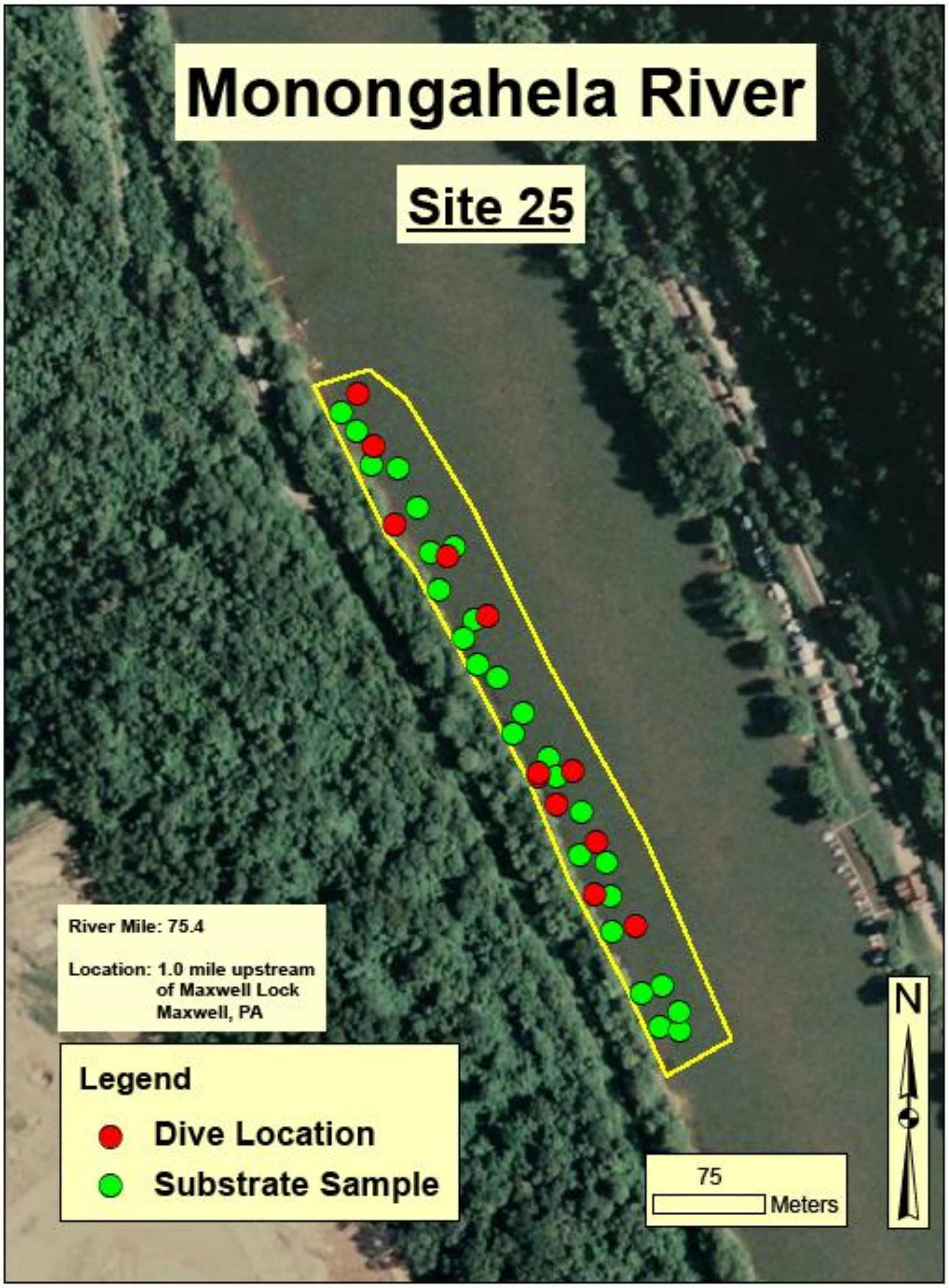


FIGURE 66. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

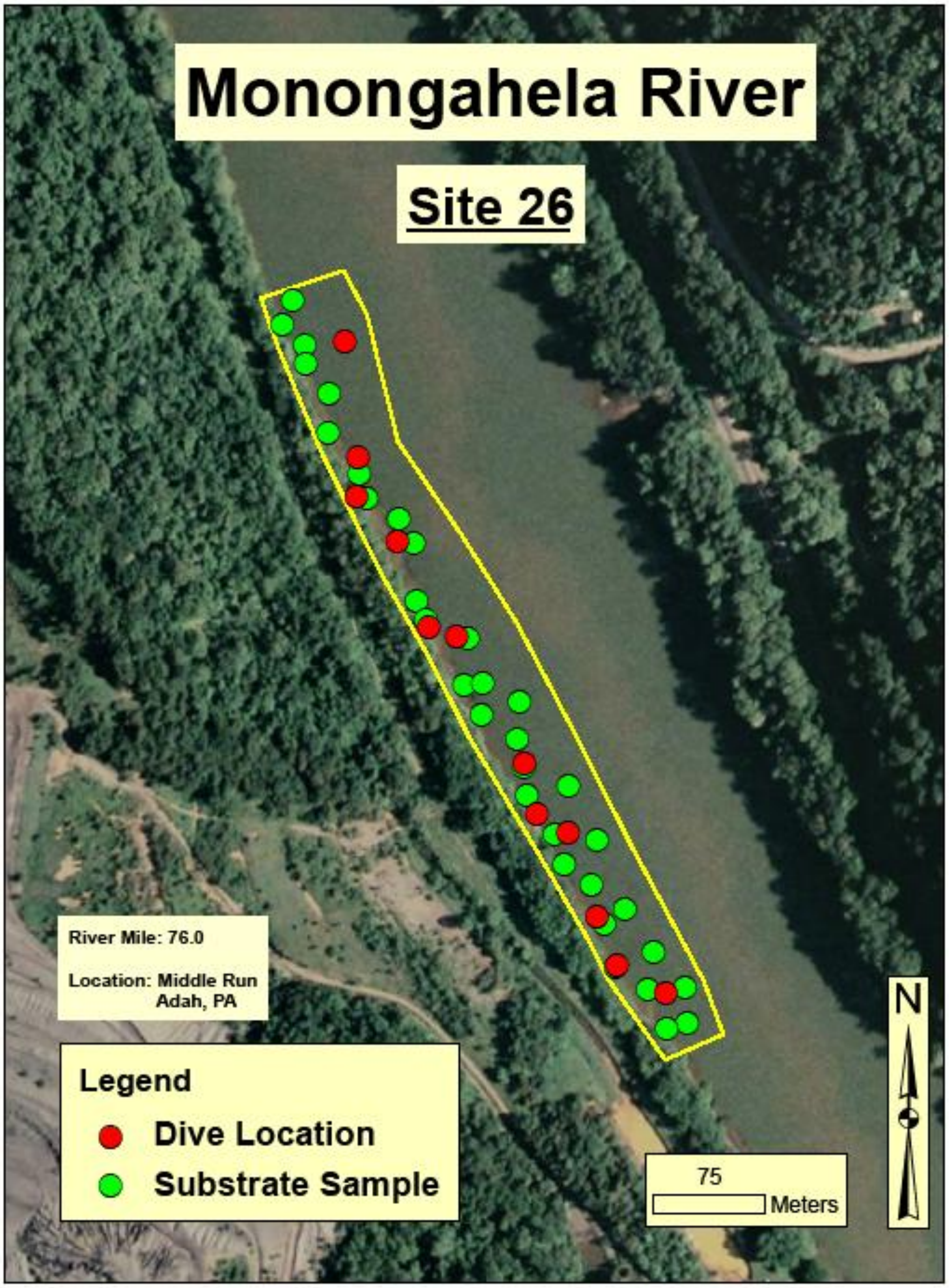


FIGURE 67. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

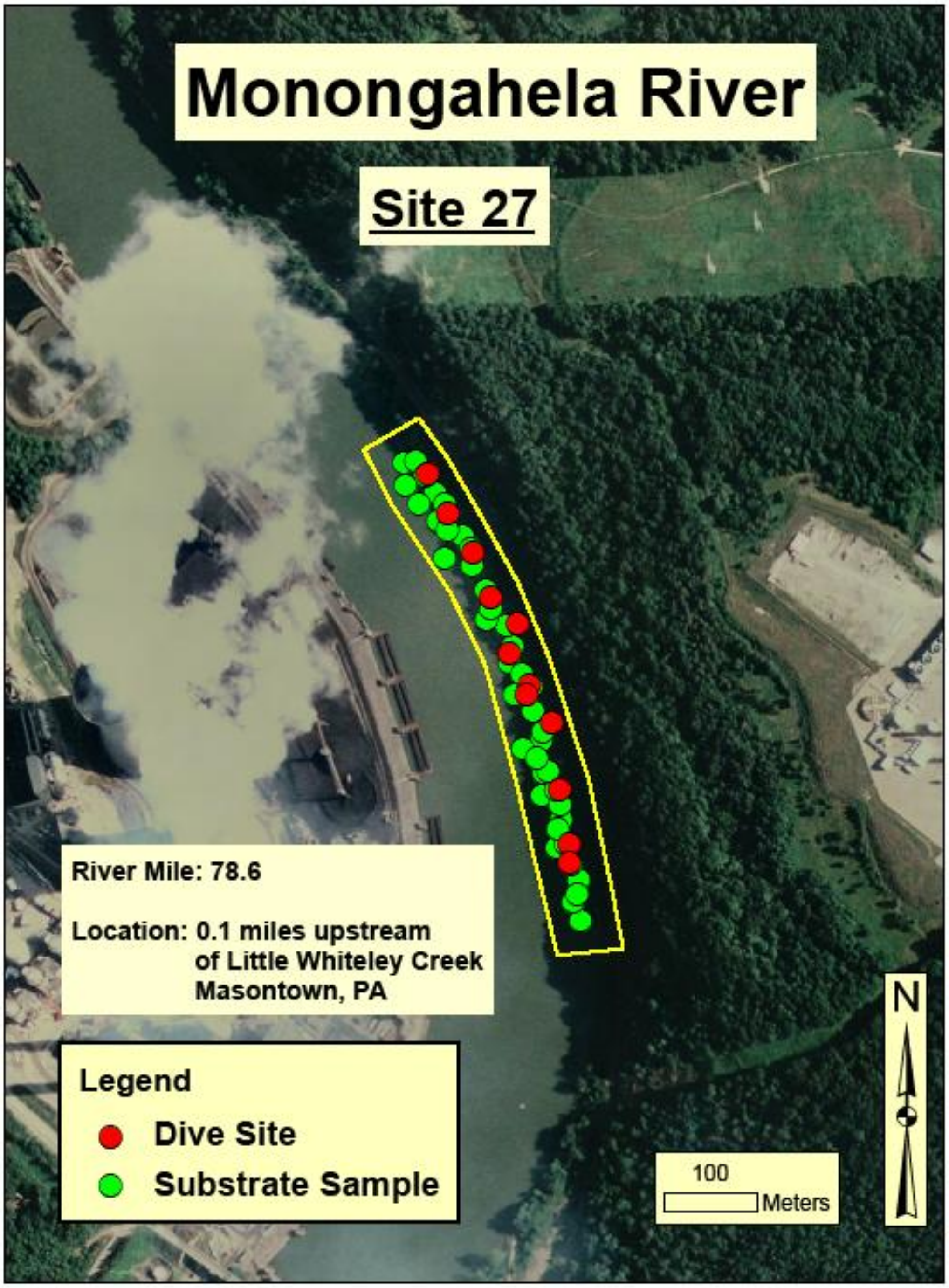


FIGURE 68. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

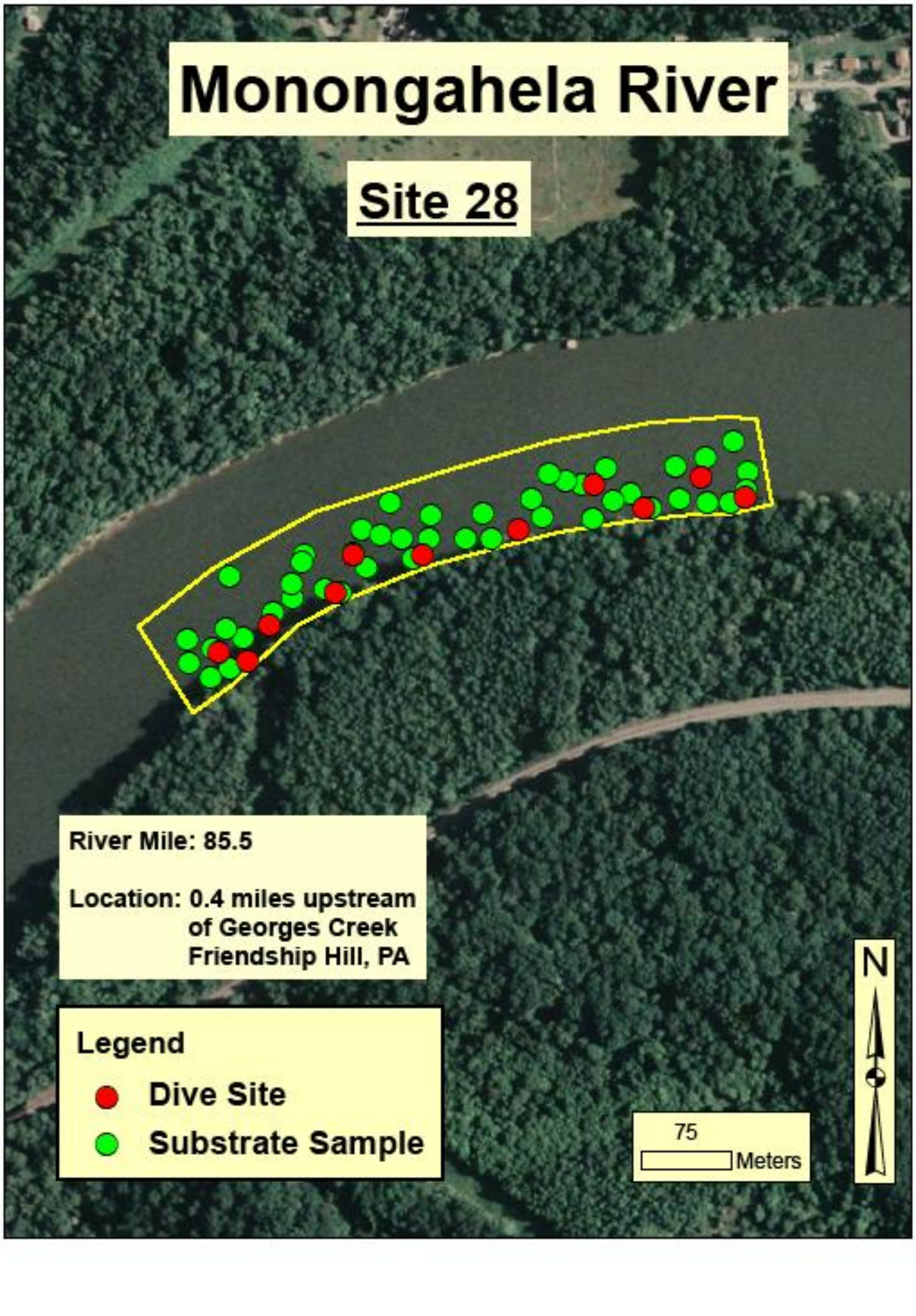


FIGURE 69. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

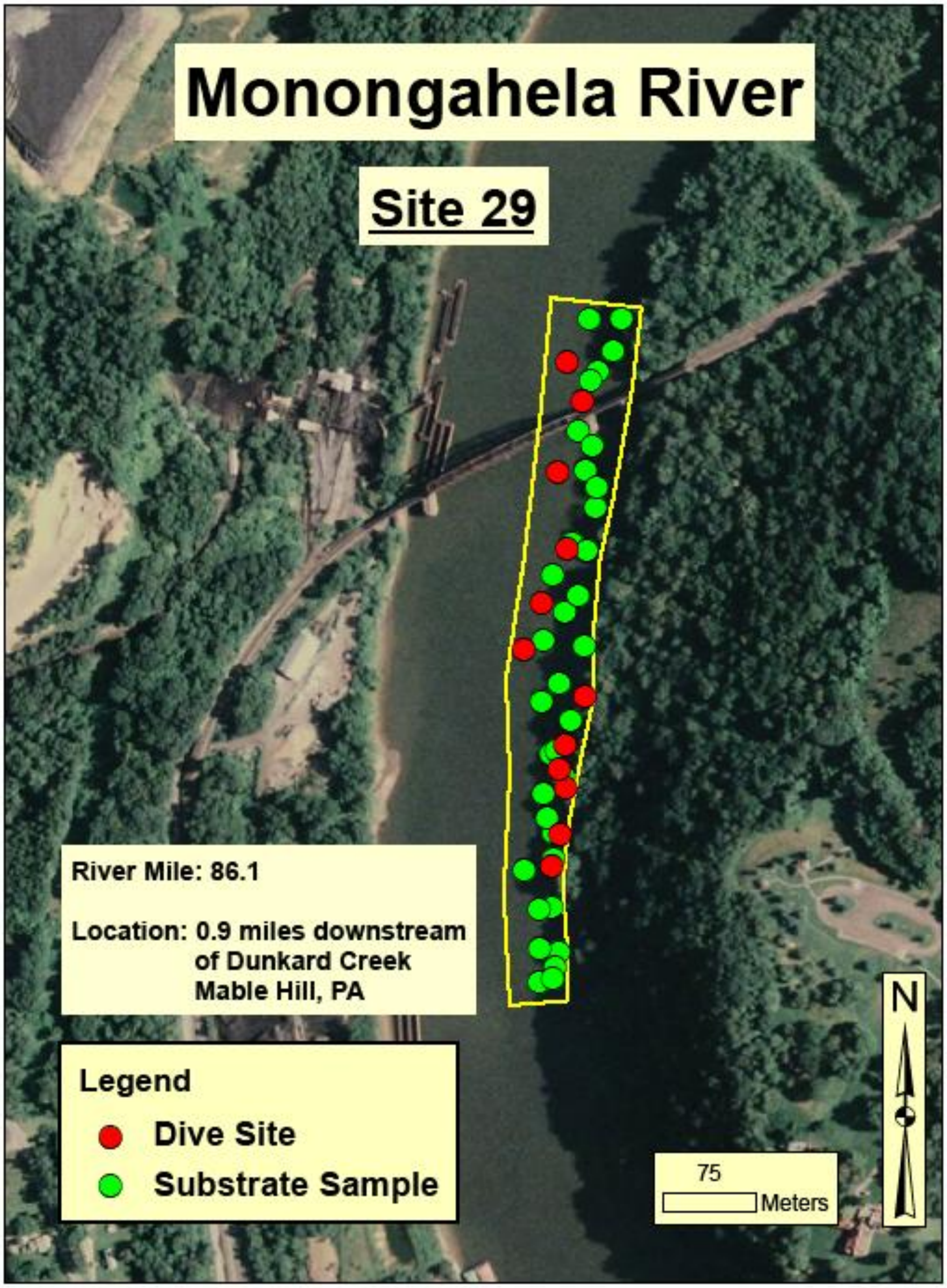


FIGURE 70. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..

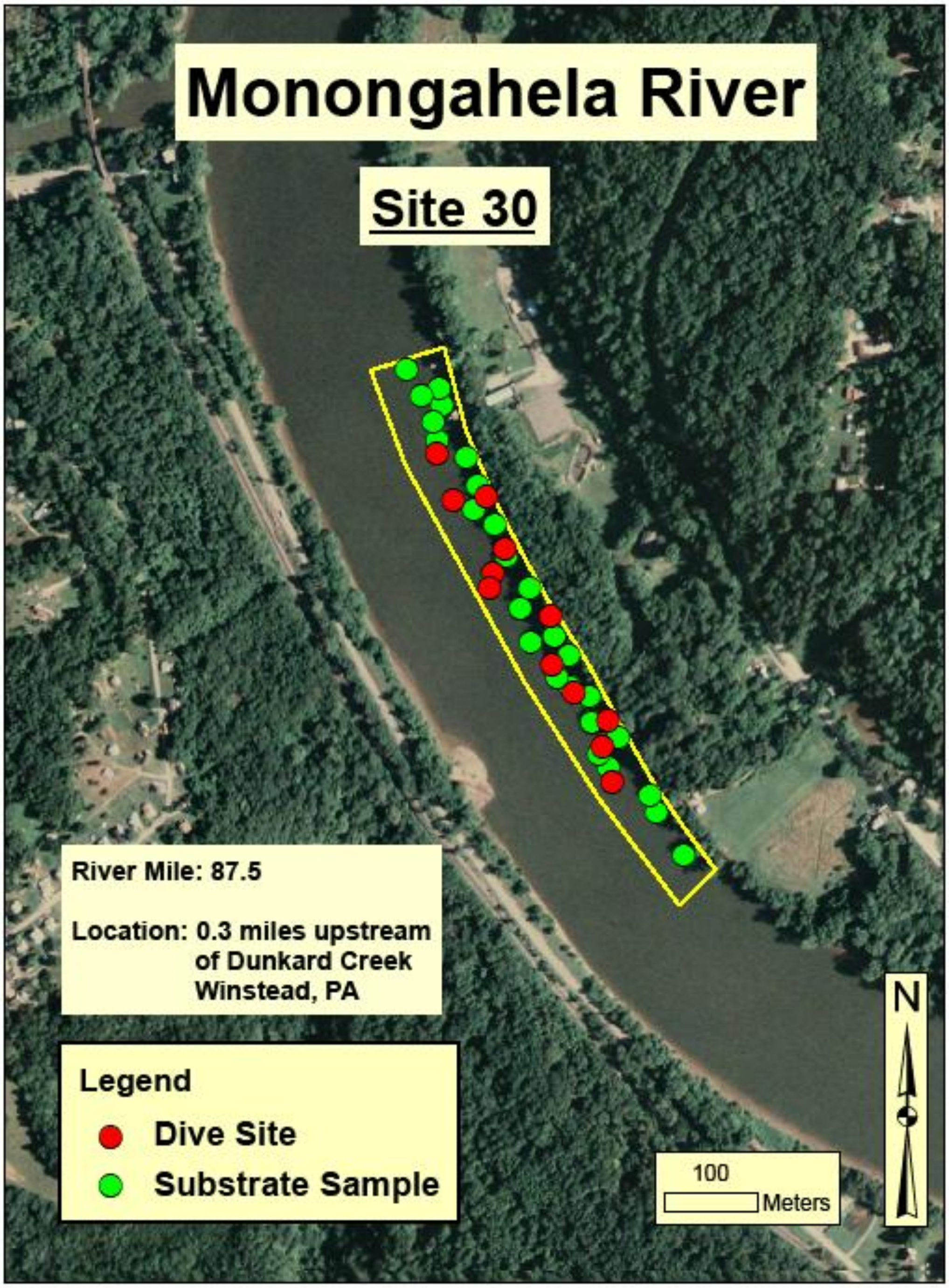
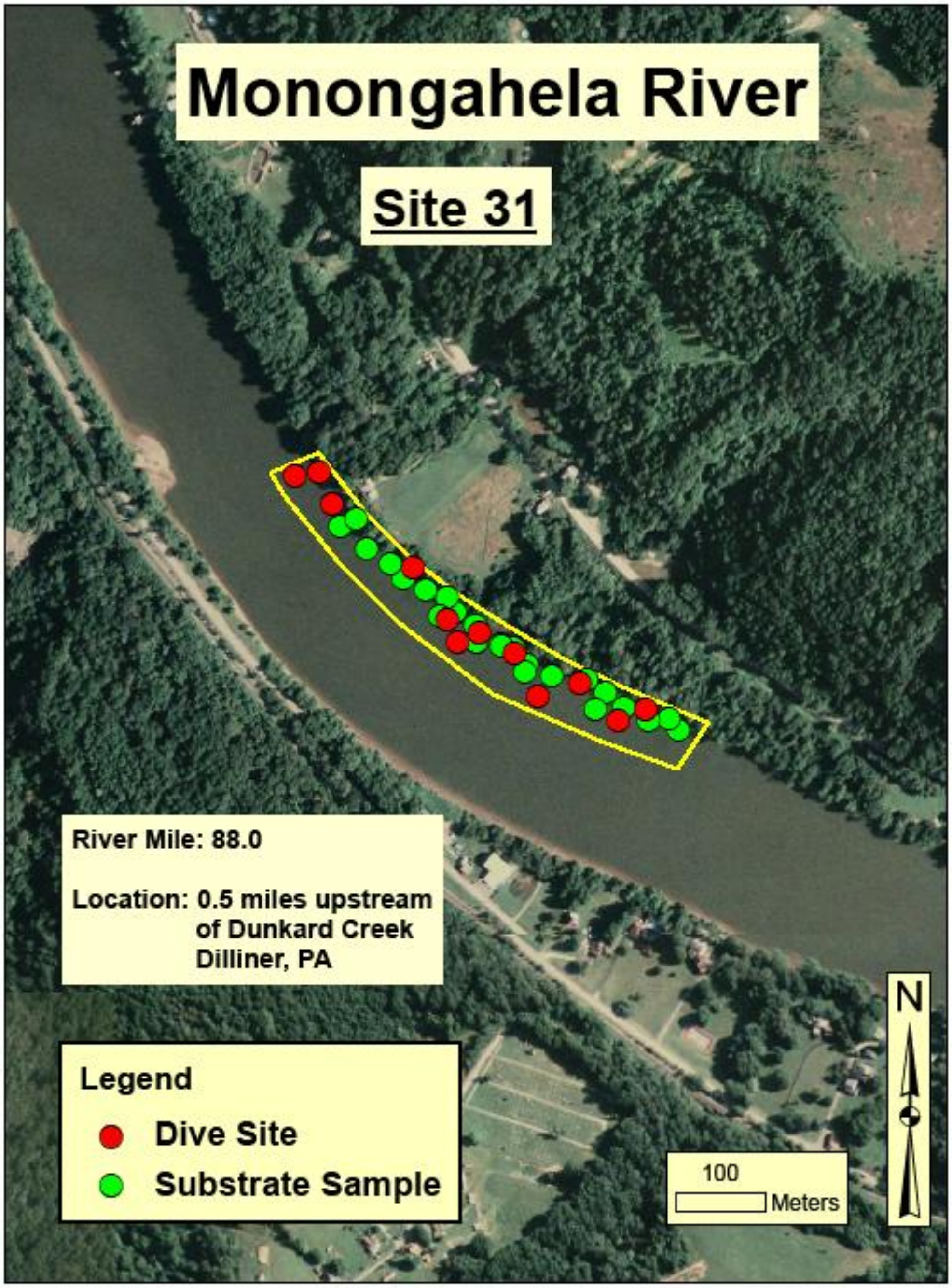


FIGURE 71. Locations of mussel surveys conducted by divers and substrate sampling on the Monongahela River, PA..



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4.0 CURRICULUM VITAE

Jonny Hart

EDUCATION

Degree: **Bachelor of Science**, University of South Florida, Tampa FL
Major: **Environmental Science & Policy** Emphasis: Chemistry
Date: May 2006

Degree: **Graduate Certificate**, Marshall University, Huntington WV
Emphasis: **Geographical Information Sciences** Graduate Credits: 12 GPA: 3.75
Date: May 2010

Degree: **Master of Science,** Marshall University, Huntington WV
Major: **Biology-Watershed Resource Science** Emphasis: **GIS**
Thesis: Mollusk and Habitat Analysis of the Monongahela River, PA Utilizing GIS
Date: May 2012 Graduate Level Credits: 42 GPA: 3.46

Specialized Skills

- Fish Assemblage Identification (Specialty: Appalachian Mtns. and Mississippi drainage)
- River Geomorphology and Fluvial Processes
- Longitudinal Stream and Cross Section survey design and assessment
- Stream Structure design, Bank Erosion Hazard Indexes, and Erosion Rate Calculations
- Freshwater Mussel Surveying and Identification (Specialty in WV,KY,PA,TN)
- Stream Restoration, Assessment, and Analysis
- EPA, WV, KY, & Orsanco Bioassessment Protocols & Indexes
- Aquatic Ecosystem Protection Plans (AEPP)
- Geographic Information Systems- ArcGIS 9.1-9.3.1 & 10
- AutoCAD Map 3D, AutoDESK CIVIL 3D 2012
- GIS Vector & Raster Analysis, Interpolation, Inverse Distance Weighting, Advanced Spatial Analyst
- Trimble, ArcPad, ArcView, ArcGlobe, ArcScene, DNRGarmin
- Sontek Sonar River Profiling, Hydrolab Multi-Parameter Water Instruments
- Electro fishing (Vessel/Backpack), Trawl Nets, Gill Nets, Kick Nets, Hoop nets, Surber, Seine, SCUBA(adv.,night,deep, hookah),
- Substrate Sampling and Analysis: Inverse Distance Weighting, Copper Pole, Wolman Pebble, Longitudinal and Cross Sectional River Profiling
- Scientific Writing Applications: Adobe Professional, Microsoft Access, Excel, Word, PowerPoint, SPSS, PC-ORD, ArcMap, ArcCatalog, SQL query, ExpertGPS, Database Management

Conference/Professional Presentations

American Fisheries Society National Conference-Pittsburgh, PA- Sept 2010
"Effects of mining activity on the fish populations in the tributaries of East Lynn Lake"

West Virginia Mine Drainage Task Force Symposium- Morgantown, WV March 2011
"Effects of mining over a ten year period on the fisheries, macroinvertebrates, and water chemistry within the tributaries of East Fork Twelvepole Creek"

Specialized Training Courses

Rosgen Stream Restoration-Level I-Fluvial Geomorphology-	February 2010
Rosgen Stream Restoration- Level II- River Morphology & Application	May 2011
WVDNR Fish ID certification-	June 2010
US Army Corps of Engineers HGM Funct. Stream Assess.Workshop-	November 2010
Trimble/Terrasync-Private 2 day course-	December 2010

WORK EXPERIENCE:

R.E.I. Consultants- Beaver, WV: 05/2010-05/2012

Title: Fisheries Biologist

Responsibilities: Fisheries collection, identification, analysis and report generation. River Geomorphology Assessment. Stream Restoration and Analysis. Macroinvertebrate collection and report generation. Wetland delineations and stream analysis. ArcGIS and AutoCAD map generation and production.

Kentucky State Nature Preserve Commission: 05/09-11/09

Title: Aquatic Biologist- Interim

Responsibilities: Conducted field surveys for endangered and threatened crayfish, mussels, and fish species. Organized and directed research volunteers for sampling protocol and safety. Processed data and information for commission reports in order to enhance species knowledge and stewardship. GIS map production and analysis.

Marshall Research Corporation: 04/08-04/09

Title: Graduate Research Assistant

Responsibilities: Large River Environmental surveying and habitat evaluation on the Ohio, Monongahela, Kanawha and Coal Rivers in West Virginia and Pennsylvania, including species identification with emphasis in freshwater mussels, invertebrates, fish, crayfish and snails.

PUBLICATIONS:

Hart, Jonny. "Freshwater mussel populations of the Monongahela River, PA and evaluation of the ORSANCO copper pole substrate sampling technique using G.I.S. interpolation with geometric means" MS thesis. EPA Environmental Monitoring & Assessment Program- Large Rivers Study. 2012

Hart, Jonny, Ed Kirk, & Randy Maggard. "Effects of mining over a ten year period on the fisheries, macroinvertebrates, and water chemistry within the tributaries of East Fork Twelvepole Creek" proceedings of West Virginia Mine Drainage Task Force Symposium. Morgantown, WV. March 2011.

Hart, Jonny & Ed Kirk "Effects of mining activity on the fish populations in the tributaries of East Lynn Lake" proceedings of the American Fisheries Society National Conference-Pittsburgh, PA- Sept 2010

Evans, Ryan & Jonny Hart. "An Analysis of the Fish Assemblage in Lower Howard's Creek, KY." Kentucky State Nature Preserve Commission Report. August 2009.

Evans, Ryan & Jonny Hart. "Freshwater Mollusk Monitoring in the South Fork Kentucky River Watershed." Kentucky State Nature Preserve Commission State Report. September 2009

RELEVANT COURSEWORK:

GRADUATE: GIS Vector Analysis, Geo-spatial Mobile Tech., GIS Principle, Ichthyology, Microbial Ecology, Malacology, Habitat Assessment, Bio-monitoring, Environmental Law, Mass Spectrometry, Geographical Information Systems (GIS)

UNDERGRADUATE: Environmental Science, Geomorphology, Wetland Env., Bio I/II, Org. Chem, Env. Policy/Politics, Geography, Geology, Calculus I/ II, Env. Ethics, Statistics, Coastal Env.,Climatology, Physics, Climate

CERTIFICATIONS- Past and Present

West Virginia Department of Natural Resources (WVDNR) Fish identification	6/2010
Geographic Information Systems-Graduate Certificate-Marshall University	5/2010
NAUI Advanced SCUBA certification (Advanced, Deep, Night)	2004-Present
NFPA Swift water Rescue Technician-Advanced	2006-Present
D.N.R. Registered Whitewater Professional: Gauley/New Rivers	2006-Present
Red Cross CPR/AED for the Professional Rescuer	2004-Present
Red Cross Nationally Certified Emergency Medical Technician (EMT-B)	2006-2009
West Virginia D.O.T. Licensed Emergency Medical Technician	2007-2009
Red Cross Wilderness First Aid	2007-2009
SOLO Wilderness First Aid	2003-2007

PROFESSIONAL EXPERIENCE PROJECTS:

WV Stream Morphology, Fisheries, and Macroinvertebrate Analysis Study (2011)
Streams: Leatherwood Creek, Ike Fork, Lilly Fork, Big Branch, Sycamore Run, Road Fork
- Directed 6 man survey crew across 46 sampling stations for fisheries survey
- Bank Erosion Hazard Index Analysis
- Stream Erosion Analysis
- Survey design and coordination
- Geomorphic Assessment and Design
- NPDES permit development and compliance

Tioga 3 Controlled Mitigation Plan (CMP) Stream Restoration Project (2010-11)
Streams: Bearpen Fork, Left Fork, Tioga
- Over 20,000 feet of stream assessment and impact analysis
- Bank Erosion Hazard Index Analysis
- Stream Erosion Analysis
- Stream restoration on over 5,000 feet of stream impact
- Geomorphic Assessment and Design
- Regulatory Mitigation Credit/Debit Analysis

Raleigh County Memorial Airport Controlled Mitigation Plan (CMP) (2010/2011)
- Stream Erosion and Habitat Assessment
- Stream Restoration Assessment
- Longitudinal and Cross Section Survey Analysis
- Substrate Analysis and Assessment

Mercer County Memorial Airport Controlled Mitigation Plan (CMP) (2010/2011)
- Stream Erosion and Habitat Assessment
- Stream Restoration Assessment
- Longitudinal and Cross Section Survey Analysis
- Substrate Analysis and Assessment
-

Little Coal River Stream Restoration Assessment (June/July 2011)
- Stream Structure Efficiency Analysis
- Directed fisheries survey across 10km of stream restoration structures
- Habitat Analysis and Assessment
-

Habitat and Macroinvertebrate Assessment and Analysis
- Numerous surveys across West Virginia, Kentucky, and Ohio
- Directed Field Crews and Surveys
- Report generation and assessment, AutoCAD Map Generation

Preliminary Jurisdictional Determinations-
WV Counties-Raliegh, Logan, Mingo, Greenbrier, Wayne, Wyoming, Nicholas
- Geomorphic description
- AutoCAD map preparation
- Report Generation

Wetland Delineation- Multiple Locations- Mercier/Raleigh Airport, Allen Creek, Mill Branch, Bailey Branch
- Soil Survey
- Trimble Mapping
- Indicator Species Identification

East Fork Twelvepole Creek, WV Fish Survey (April and October 2010)
- Project leader-4 man team
- Fisheries identification
- Backpack Shocking
- Survey design and coordination

Kiah Creek, WV Fish Survey (April and October 2010)
- Project leader-4 man team
- Fisheries identification
- Backpack Shocking
- Survey design and coordination

Trough Fork & Big Laurel Creek, WV Fish Survey (April and October 2010)
- Project leader-4 man team
- Fisheries identification
- Backpack Shocking
- Survey design and coordination

South Fork Kentucky River Mussel & Snail Survey (June 09 – October 09)
- SCUBA, Snorkel, & Hand sampling for unionid mussels
- SCUBA habitat assessment, substrate mapping
- Freshwater Snail Sampling, Identification, & Cataloging

Monongahela, PA Mussel and Bathymetry Survey (June-August 2008)
- SCUBA sampling for unionid mussels
- SCUBA habitat assessment, substrate mapping
- ORSANCO/EPA Protocol Copper Pole Substrate Sampling
- Sontek Sonar River Velocity Profiling
- Surber Macro-invertebrate collection

Lower Howards Creek, KY - Fish Assemblage & Bioassessment (July 2009)
- Substrate mapping (Wolman pebble count)
- Backpack electro fishing and Seining
- Index of Biotic Integrity Assessment
- Aquatic community surveys & GIS Habitat Mapping

Susquehanna River, MD Trawling/Diving (August 2008)
- Benthic trawling for darters and other fishes
- SCUBA sampling for unionid mussels
- SCUBA habitat assessment, substrate mapping and Surber sampling

Little Coal River Aquatic Survey (June 2008)
- Bathymetric mapping
- Substrate mapping (Orsanco copper pole)
- Sontek Stream velocity mapping
- Kick-net macro invertebrate collection

Three Ponds Nature Preserve Crayfish and Fish Survey (June-July 2008)
- Native Fish population sampling and endangered Cypress Minnow Evaluation
- Collected native crayfish populations
- Identified specimens in the lab and in the field to species level
- Completion of 38 variable field data sheet

Stinking Creek KY Blackside Dace Survey (Sept 2009)
- Sampled endangered Blackside Dace population
- Utilized non-lethal collection and field Identified

Tygart River, KY Botanical Study (Sept 2009)
- Surveyed for rare mountain maple (*Acer spicatum*)
- Conducted field searches for Canadian yew (*Taxus canadensis*)
- Field assessed potential anthropological impacts

Rockcastle River, KY (Cumberland Plateau) Fish and Mussel Sampling (August 2009)
- Surveyed for endangered mussels via snorkel and hand surveying
- Sampled and Field Identified native fish and mussel populations
- Freshwater snail collection and lab identification
- Assisted U.S. Forest service surveying and sampling

Kanawha River, WV DNR sanctioned Native Turtle Survey (April 2008)
- Native turtle population Survey
- Field identified, tagged, and logged turtles
- Utilized hoop net traps for collection

IUCN Red listed Louisville Crayfish Survey (*Orconectes jeffersoni*) (September 2009)
- Collected Crayfish throughout Louisville creeks, impoundments and ditches
- Field Identified *jeffersoni* and preserved other native populations for cataloging
- Snail population sampling and collection as well

REFERENCES: Available Upon Request