Experimental Stocking of American eels in the Susquehanna River Watershed

2019 Annual Report / Final Report

Mitigation Project for: City of Sunbury, Riverbank Stabilization Project
DA Permit Application Number: NAB 2005-02860-PO5

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SUMMARY

American Eel (*Anguilla rostrata*) occupies a unique niche in estuarine and freshwater habitats along the Atlantic coast but range-wide, the population has declined during recent decades. The Chesapeake Bay watershed supports a large portion of the eel population, but much of the watershed is inaccessible due to dams on the lower part of the Susquehanna River. In 2008, the U.S. Fish and Wildlife Service (USFWS) began stocking eels above dams to allow them access to upstream areas. Laboratory studies conducted by the U.S. Geological Survey (USGS) indicate that eels are a good host for the common freshwater mussel, Eastern Elliptio (*Elliptio complanata*) in the Susquehanna River. While Eastern Elliptio were present in the watershed, they were less abundant than in nearby watersheds and there were very few juveniles at the beginning of this study. Low abundance and lack of recruitment of Eastern Elliptio in the Susquehanna River may be related to the lack of eel passage past the dams. To explore this question, USFWS and USGS conducted targeted eel stocking in tributaries to the Susquehanna River in 2010, 2011, 2012, and 2013 and monitored both Eastern Elliptio and American Eel populations. Monitoring conducted in 2014 and 2019 indicates increased Eastern Elliptio recruitment and population growth as well as maturation of stocked eels. Our results suggest that permanent eel passage at the 4-mainstem Susquehanna River dams would likely improve ecological function in the watershed by increasing recruitment of Eastern Elliptio. The presence of healthy freshwater mussel beds provides streambed stability, water filtration, and increased macroinvertebrate biodiversity.

INTRODUCTION

American Eel (*Anguilla rostrata*) populations have declined along the Atlantic coast (ASMFC 2017). The Chesapeake Bay and tributaries support a large portion of the remaining coastal eel population. However, hydropower dams block natural eel passage to most of the Susquehanna River, a large tributary to the Chesapeake Bay. There are four large hydropower dams in the lower Susquehanna River (Figure 1). While fish passage facilities exist at each of the hydropower dams, each facility was designed to pass migrating shad and river herring. Therefore, eel passage was largely unsuccessful in those fishways. Before dams were constructed, the annual harvest of silver eels in the Susquehanna River was nearly one million pounds (Miller et al. 2010). The Pennsylvania Fish and Boat Commission (PA FBC) stocked eels in the Susquehanna River and its tributaries intermittently from 1936 to 1980 (Miller et al. 2010). However, at the beginning of this project in 2010, there was no commercial harvest or recreational fishery for eels above the dams (pers. comm. Andrew Shiels PA FBC). Dams on the Susquehanna River not only eliminated a once abundant eel fishery; they likely had a profound effect on the way the ecosystem functions. Eels may play an integral part in supporting freshwater mussel populations in the Susquehanna River.

Research conducted by the U.S. Geological Survey (USGS), Northern Appalachian Research Laboratory (NARL) and the U.S. Fish and Wildlife Service (USFWS), Maryland Fish and Wildlife Conservation Office (MDFWCO) indicates that American Eel is a successful host fish for the freshwater mussel, *Elliptio complanata* (Eastern Elliptio) (Lellis et al. 2013). The larvae (glochidia) of most freshwater mussel species must parasitize a host fish to complete metamorphosis to the independent juvenile life stage. Glochidia from Eastern Elliptio, collected by NARL from the Susquehanna River, had higher metamorphosis success rates on American Eels (≥ 90% success) than on other fish species commonly found in the Susquehanna River (Lellis et al. 2013). In many Atlantic draining watersheds, Eastern Elliptio comprise the most abundant biomass of any fauna in the watershed and can provide great filtration capacity (Kreeger et al. 2018). For example, the estimated 280 million Eastern Elliptio in the Delaware River have the potential to filter between 2 billion and 6 billion gallons of water and remove 78 tons of sediment from the water column each day (Spooner and Lellis 2010). However, Eastern Elliptio is less abundant in the Susquehanna River watershed than in nearby watersheds such as the Delaware and Potomac (Lellis 2002, Blakeslee et al. 2018; PAFBC unpublished data; Jim McCann, Maryland Department of Natural Resources, pers. comm).

In 2008 and 2009, Galbraith et al. (2018), conducted freshwater mussel surveys in the Susquehanna River watershed to assess whether recruitment was occurring in Eastern Elliptio populations. Recruitment here refers to the number of individuals surviving to the independent juvenile life stage, large enough to be enumerated (~5mm) in surveys of Eastern Elliptio populations. Biologists identified 13 tributaries to the Susquehanna River, based on previous surveys (PAFBC, unpublished data), as having relatively high density of Eastern Elliptio (≥ 30/hour). In each of these tributaries, a 3.2 km (2 miles) snorkel survey was conducted and a 200 m section was selected with high density of Eastern Elliptio. Within the 200 m section selected in each tributary, biologists conducted mussel surveys of randomly selected 0.25 m^2 quadrats, following the methods of Strayer and Smith (2003). Based on these surveys, two streams with relatively high abundance of Eastern Elliptio were selected for this project: Buffalo Creek and Pine Creek. At these and other sites above Conowingo Dam, Galbraith et al. (2018) found zero or few (< 3) juvenile (< 40 mm) Eastern Elliptio. In contrast, in the mainstem Susquehanna River and tributaries below Conowingo Dam, where eels were present, juvenile Eastern Elliptio were found. These results indicate that many of the Eastern Elliptio populations at upstream sites had little or no successful reproduction and/or recruitment when surveyed in 2008. If eels are important to successful reproduction and the subsequent recruitment of juveniles in Eastern Elliptio populations in the Susquehanna River, restoring eels could also restore mussels, which could result in improved water quality in the system.

In order to test the hypothesis, “Eels are important to Eastern Elliptio Recruitment in the Susquehanna River Watershed” and as mitigation for the City of Sunbury, Riverbank Stabilization Project, the objectives of this project are to:

1. Stock juvenile American Eels (elvers) in upstream tributaries to the Susquehanna River with existing Eastern Elliptio populations (Buffalo Creek, Union County, PA, and Pine Creek, Tioga County, PA).

2. Monitor eel presence/absence at 2 locations in each tributary during each of the three years of stocking (2010, 2011, and 2012), year 5 (2014) and year 10 (2019) of the project.
3. Survey freshwater mussel populations in each tributary to collect baseline mussel population data and assess recruitment to the mussel populations in year 5 (2014) and year 10 (2019) of the project.

METHODS

Eel Stocking

Based on eel data (number of eels/km) collected in tributaries to the Susquehanna River and Chesapeake Bay below Conowingo Dam, a rough estimate of capacity for eels in upstream tributaries was calculated. We estimated an average density of eels at 529 eels/km using data collected by Maryland Department of Natural Resource (MD DNR), Maryland Biological Stream Survey (MBSS), in four tributaries downstream of Conowingo Dam: Big Elk Creek (Cecil County, MD), Furnace Bay (Cecil County, MD), Little Elk Creek (Cecil County, MD), and Northeast River (Cecil County, MD). We calculated the number of eels needed to achieve a similar density of 529 eels/km at stocking sites by multiplying the number of mainstem stream kilometers above the stocking site by the average density. Based on these calculations and the projected feasibility of capturing eels for stocking, we proposed to relocate 60,000 eels to each tributary, Buffalo Creek and Pine Creek, over a three-year period (2010 through 2012).

We collected eels from glass eel and elver sampling sites in MD for stocking in Buffalo and Pine Creeks. Glass eels are unpigmented eels found close to the Atlantic Coast while elvers are pigmented, older and typically longer in length (Wang and Tzeng 1998). The Atlantic States Marine Fisheries Commission (ASMFC) requires all states, including MD DNR, to conduct

Young-of-Year (YOY) eel monitoring. MD DNR helped us obtain glass eels from their sampling devices located at a bridge culvert in Turville Creek (Ocean City, MD) and at the Bishopville Dam on Bishopville Prong (Bishopville, MD). Following collection, glass eels were held by USGS in captivity at the Northern Appalachian Research Lab (NARL) in Wellsboro, PA until they matured to pigmented elvers (55-94 mm), typically 1-3 months. We stocked these eels in Buffalo Creek and Pine Creek (Table 1). The USFWS collected elvers (90-150 mm) from their collection device located immediately downstream of Conowingo Dam. The USFWS eel ramp consisted of a covered cable tray lined with landscaping cloth (Enkamat) and was located at the base of Conowingo Dam. Water from the Susquehanna River was pumped to the top of the cable tray ramp where it flowed down the Enkamat to attract elvers. Elvers crawled up the ramps and fell into tanks at the top of the ramp. Aerated water was circulated through collection tanks to keep elvers in good health. We sedated, measured, and counted eels in the collection device. We estimated large numbers of eels volumetrically and estimated length based on a subsample. We held elvers in tanks at Conowingo Dam until there were enough to stock in Buffalo Creek and Pine Creek (Table 1).

We stocked eels in close proximity to Eastern Elliptio beds to encourage association between Eastern Elliptio glochidia and eels (Figure 2) at 3 locations in Buffalo Creek: Strawbridge Rd. Bridge (40.9856 N, 76.93237 W); the footbridge on Rt. 1003 (40.98105 N, 76.95134 W); and near the U.S. Penitentiary in Lewisburg, PA (40.98078 N, 76.924114 W). The mouth of Buffalo Creek, near Lewisburg, PA is approximately 9 miles north of Sunbury, PA on the West Branch of the Susquehanna River. In Pine Creek, we stocked eels near high densities of Eastern Elliptio at 4 locations (Figure 2): Owassee Rapids (41.71568 N, 77.45543 W); Darling Run Access (41.74368 N, 77.43394 W); Marsh Creek Boat Ramp (41.74466 N, 77.42775 W); and Ansonia Bridge, Ansonia, PA (41.73671 N, 77.43036 W) (Table 1). Pine Creek, which has its confluence with the West Branch of the Susquehanna River at Jersey Shore, PA, has the highest density of Eastern Elliptio found in previous surveys. We documented and reported all stocked eels to the Pennsylvania Fish and Boat Commission as part of the requirements of the Scientific Collecting Permit Number 354, Type 2.

Fish survey

To evaluate eel stocking success, including survival, growth, and impacts on the fish community, we conducted electrofishing surveys using 4 backpack and 1 barge electrofishing units in 2010, 2011, 2012, 2014 and 2019. The barge electrofisher provided electricity to two attached anodes. Using methods similar to MD DNR MBSS (2007), at two locations in each creek (Buffalo and Pine), we blocked off 75 meters of stream using ¼" mesh block net. We conducted 2 passes with the electrofishing units and quantified the number of fish caught and time surveyed to calculate a catch per unit effort (CPUE) for each fish species. We measured the biomass of eels relative to all fish captured and calculated a CPUE in grams per hour. A subsample of eels was returned to the lab to assess stomach contents, presence of the swim bladder parasite *Anguillicoloides crassus*, and remove otoliths for aging. We calculated abundance estimates for eels in the surveyed area using the methods of Seber and LeCren (1967). Differences in eel lengths between years were determined using a two-sample t-test in EXCEL. Impacts of eel reintroduction on the fish community were assessed by looking at changes in biodiversity in genus over time using the Shannon-Wiener Diversity Index (Shannon 1948). We calculated Spearman rank correlation coefficients to determine if there are correlations between eel CPUE (g/hr), discharge (from USGS 01548500 Pine Creek at Cedar Run, PA and the surrogate for Buffalo Creek, USGS 01555000 Penns Creek at Penns Creek, PA) and CPUE of fish genus.

Eel Growth

In addition to the electrofishing surveys at the stocking locations in Buffalo Creek and Pine Creek, we conducted an electrofishing survey upstream and downstream of the Buffalo Creek stocking locations each year from 2012-2019 (Figure 3) as part of a separately funded PIT (Passive Integrated Transponder) tagging study. We used two backpack electrofishing units to capture American Eels at several locations ranging from 2.4 km upstream to 2 km downstream of stocking locations. We measured captured eels and tagged those with lengths over 200 mm by inserting PIT (Passive Integrated Transponder) tags into the dorsal musculature. We then released captured eels near their capture location. For comparison among size groups we also used Kruskal-Wallis tests and post-hoc Conover-Iman tests. Analyses were carried out in Systat (ver. 13.0).

From 2017-2019, we sampled 12 sites in upstream areas of Buffalo Creek for eels (Figure 3). These sites were selected based on accessibility and to represent a range of stream orders and distances from stocking locations. At each site, one or two backpack electrofishers were used depending on stream width. Each site was sampled in an upstream direction for approximately twenty minutes. Eel handling and tagging followed the same procedures as the assessments of near-stocking locations. We measured stream width (m) and recorded latitude and longitude (dec. deg.) of site starting and ending locations.

Mussel survey

We conducted baseline mussel surveys in Buffalo Creek in 2010 and in Pine Creek in 2008 and post eel stocking surveys in both creeks in 2014, 2015 and 2019. We conducted qualitative searches in a 3.2 km (2 mile) stream reach in each of Buffalo Creek and Pine Creek using snorkeling equipment. We recorded the number of mussels and the search time after each 200-meter section to determine a CPUE. Within the surveyed area, we identified a 200-meter section of stream, approximately 6000 m^2 in area, with a high mussel density relative to the other 200-meter sections surveyed in that creek. The 200-meter section selected in 2010 was resurveyed in Buffalo Creek in 2014 and 2019. However, in Pine Creek, high water in 2014 affected our ability to resurvey the same 200-meter section selected in 2008. Therefore, we selected a shallower section upstream for 2014 and 2019 surveys. To ensure consistency, during the off year of 2015, when there were low water conditions, we returned to conduct a survey at the baseline Pine Creek survey site.

In the selected 200-m sections, we conducted quantitative surveys to estimate mussel abundance and assess presence of juvenile mussels. These areas were selected for quantitative surveys under the assumption that if we were going to find juvenile Eastern Elliptio, it would likely be in the area of high mussel density. We sampled 0.25 m^2 quadrats at each survey location, selected using a systematic random design with multiple random starts (Strayer and Smith 2003). We excavated all quadrats to 10 cm or to hardpan and sifted sediment through a 5-mm^2 mesh screen in order to detect juvenile mussels. We recorded the number of each species and measured length of each mussel. Quantitative and qualitative survey methods followed accepted protocol developed by Strayer and Smith (2003). We analyzed the quantitative survey data to determine abundance and density using the Mussel Estimation Program (Version 1.1.4) developed by David R. Smith (USGS, Leetown Science Center, Leetown, WV).

RESULTS

Eel Stocking

We stocked over 240,000 American Eels near high-density Eastern Elliptio locations in Buffalo Creek and Pine Creek. Between June of 2010 and August of 2013, we stocked 118,742 eels at three locations in Buffalo Creek (Table 1). Between June of 2010 and June of 2012, we stocked 122,049 eels at 4 locations in Pine Creek (Table 1). This exceeded the proposed 60,000 eels in each creek. We originally intended to only stock elvers collected at Conowingo Dam but because we were unsure that we would be able to attain the proposed stocking numbers, we also stocked glass eels collected in Maryland and reared at NARL. Since the glass eels were smaller than elvers collected below Conowingo Dam, we were concerned that they might be more subject to predation, so we increased the number stocked.

Fish Survey

In 2019, we collected 838 individuals of 27 fish species in Buffalo Creek, 200 individuals of 25 fish species in Pine Creek (Table 2). Relative abundance by family indicates that eels made up a greater proportion of the population at Buffalo Creek sampling sites in 2014 (18%) than in 2012 (9%) (Figure 6). The same is true in Pine Creek where relative abundance was higher in 2014 (9%) than 2012 (5%). However, from 2014 to 2019, the relative abundance of eels decreased in Buffalo Creek to 1.9 % and in Pine Creek to 2.4% of the total number of fish caught.

We captured 16 eels in Buffalo Creek in 2019 with a total mass of 3.2 kg resulting in an average of 200 g/eel. This was an increase from the average in 2014 (18.02 g/eel). Eels comprised 12.3 percent of the total biomass of captured fish in Buffalo Creek which is similar to the percent of the fish biomass comprised of eels in 2014 (12.9 percent) (Table 2). Overall there were significant differences in body size from 2011 to 2019 (Two Sample t-Test: $p < 0.001$) in Buffalo Creek. Between 2011 and 2019, the mean length increased from a mean of 137 mm

(S.D. ± 24 mm) to 431 mm (S.D. ±85) (Figure 4). While the number, CPUE and density (eels/m^2) of eels decreased from 2014 to 2019, the average eel length (mm) increased and percent biomass was similar between 2014 and 2019 (Table 3).

In Pine Creek, we captured 29 eels with a total mass of 4.8 kg. The average weight of Pine Creek eels was 164 g/eel in 2019 which was higher than the average weight in both 2014 (39.0 g/eel) and 2012 (4.5 g/eel). The eel biomass comprised 44.7 percent of total biomass of fish in 2019 which was higher than in 2014 (39.8 percent). In Pine Creek, the mean body size was also significantly different between 2011 and 2019 (Two Sample t-Test: $p < 0.001$). Mean length increased from 137 (S.D. ± 46) in 2011 to 424 mm (S.D. ± 30) in 2019 (Figure 5). As in Buffalo Creek, the number, CPUE and density (eels/m^2) of eels in Pine Creek decreased from 2014 to 2019, but the average eel length (mm) increased and percent biomass was similar between 2014 and 2019 (Table 3).

Stomach contents of a subsample of eels returned for lab dissection from Buffalo Creek in 2014 (n = 38), were comprised of crayfish, water pennies, caddisfly larvae, and other unidentifiable macroinvertebrates. The number of eels infected with a swim bladder parasite (*Anguillicola crassus*) ranged from 10% in 2010 to 34% in 2014. Stomach contents were not analyzed in 2019.

Biodiversity of fish, measured by the Shannon-Wiener Diversity Index, increased in Buffalo Creek from 2010 (1.78) to 2014 (2.44) and was similar in 2019 (2.33) (Table 4). In Pine Creek, there was also an increase in diversity from 2010 (1.88) to 2012 (2.36) and was similar in 2014 (2.20) and 2019 (2.12) (Table 4). Although the CPUE (#/hr) of eels in Pine Creek and Buffalo Creek decreased in 2019, the mass (g) of eels capture per hour increased. Over the same period, the CPUE (#/hr) decreased in the most common genera (*Etheostoma,* *Percina, Pemephales,* and *Notropis*; Figure 7). This decline in several common genera in Buffalo and Pine Creeks is correlated with the higher mass of eels caught per hour but is similarly correlated with higher discharge in 2014 and 2019 (Table 5). In Pine Creek all correlations with genera (#/hr) (≤ - 0.05 or ≥ 0.5) are in the same direction amongst eel CPUE (g/hr) and discharge.

Eel Growth

During electrofishing surveys conducted between 2012 and 2019 to assess eel growth, eels were recaptured upstream and downstream of the stocking locations in Buffalo Creek. The CPUE increased from 2012 (34.8 eels/hr) to 2015 (64.6 eels/hr) and remained steady through 2017 (55.5 eels/hr) but decreased in 2018 (29.8 eels/hr) and 2019 (19.8 eels/hr) (Table 6).

We PIT tagged 141 eels in 2019 and a total of 1,755 from 2012 to 2018 in Buffalo Creek. We returned all eels near their capture locations, except those we kept for dissection. A total of 263 PIT tagged eels were recaptured from 2013 to 2019 (Table 7). Similar to the CPUE, the recapture number decreased from a high of 75 in 2017 to 47 in 2019.

Of all recaptured eels, average growth rate was 47.8 mm/yr (SD ±23.1). Range of yearly growth rates from recaptured fish was -5.8 to 116.7 mm/yr (Figure 8). Only one individual had negative growth, which could be due to measurement error. The lowest non-negative growth rate observed was 2.1 mm/yr (2 individuals). Growth rate significantly differed between males, females, and unsexed eels, for all pooled data (Kruskal-Wallis $H=74.773$, $p<0.001$; Conover-Iman tests $p<0.001$). Females grew significantly faster than males and unsexed eels. Females grew at an average rate of 69.7 mm/yr (SD: ±20.5), while males grew the slowest at an average of 32.0 mm/yr (SD ± 9.6). Unsexed eels grew an average of 43.9 mm/yr (SD ± 20.9).

From 2017-2019, 61 eels were captured at 10 of 12 sites sampled in upper Buffalo Creek watershed. Relative abundances for upper watershed sites ranged from 1.5-14.0 eels per hour (Avg. 4.7, SD ±3.3), which is lower than sites sampled near stocking locations. Catch per unit effort increased over time for sites 2, 5, 8 and 11. We did not capture any eels at sites 1 or 10. Variations in catch per unit effort occurred over time at other sites (Table 8). All 61 eels captured at upper watershed sites were large enough to be tagged. Total lengths ranged from 232-700 mm (Avg. 473.1 mm, SD ± 121.1; Figure 9). We recaptured two eels at upstream sites (one at site 5 and one at site 4, both recaptures occurred in 2019).

Mussel Survey

<u>Buffalo Creek</u>

In 2019, we conducted snorkel surveys for freshwater mussels for 15.9 search hours in 3.2 km of Buffalo Creek. We detected 1,396 Eastern Elliptio, 8 Creeper (*Strophitus undulatus)*, and 2 Yellow Lampmussel (*Lampsilis cariosa*). Of the mussels found during the snorkel survey, 99.3% were Eastern Elliptio. The cumulative CPUE was 87.7 Eastern Elliptio per hour, with individual 200-m sections ranging between 18.8 and 186.3 Eastern Elliptio per hour. We used this data to select the same 200-meter quantitative survey section (180.1 Eastern Elliptio/ hour) in 2019 as was surveyed in 2010 and 2014.

In 2019, we excavated 69 m^2 (276 quadrats) of the 4,792 m^2 area in the 200-meter section to quantitatively survey for mussels in Buffalo Creek. We detected two species, Eastern Elliptio (333 found) and Green Floater (*Lasmigona subviridis*)(1 found). The estimated abundance of Eastern Elliptio in 2019 (27,467, SE ± 3647.7) was similar to the estimated abundance in 2014 (26,114, SE ± 2090.9) and estimated abundance in 2010 (27,249, SE ± 1831) (Table 9). The estimated density in 2019 (4.69 Eastern Elliptio/m^2, SE ± 0.661) was also not different from the density in 2014 (5.59 Eastern Elliptio/m^2, SE ± 0.41) or 2010 (5.44 Eastern Elliptio/m^2, ± 0.37). However, the average length of Eastern Elliptio was lower in 2019 (74.6 mm ± 17.0) than the average length in both 2014 (79.1 mm, SD ± 16.9) (Two Sample t-Test: $p < 0.001$) and 2010 (82.1 mm, SD ± 14.9) (Two Sample t-Test: $p < 0.001$) (Figure 10). In 2019, we found 18 juvenile Eastern Elliptio (< 40 mm) in Buffalo Creek in comparison with 6 juveniles found in 2014 and 3 juveniles found in 2010.

Pine Creek

In the summer of 2019, we conducted qualitative surveys in 3.2 km of Pine Creek. In the 25.8 survey hours spent in this 3.2 km section, 3,347 individuals of 7 species were detected: 2,967 Eastern Elliptio; 73 Creeper; 269 Brook Floater; 15 Green Floater; and 14 Elktoe (*Alasmidonta marginata*); 6 Yellow Lampmussel, and 1 Triangle Floater (*Alasmidonta undulata*). Of the mussels found during the survey, 88.6% were Eastern Elliptio. The cumulative CPUE was 114.9 Eastern Elliptio per hour with individual 200-meter sections ranging from 3.5 Eastern Elliptio per hour to 439.6 Eastern Elliptio per hour. Using this data, we selected the same 200-meter section in 2019 that we surveyed in 2014 (439.6 Eastern Elliptio/hour) in which to conduct the quantitative survey. In 2019, we did not survey the 200-meter section surveyed in 2008 and 2015 due to high water.

In 2019, we quantitatively surveyed an area of 6,084 m^2 in the selected 200-meter section in Pine Creek. In the 97.5 m^2 (390 quadrats) area excavated for the survey, 950 Eastern Elliptio were detected. The estimated abundance of Eastern Elliptio in 2019 (97,862, SE ± 6,722) was almost three times the estimated abundance of Eastern Elliptio in 2014 (28,257, SE ± 1,114). The estimated density in 2019 (9.6 Eastern Elliptio/m^2, SE ± 0.66) was almost double the estimated density in 2014 (4.6 Eastern Elliptio/m^2, SE ± 0.18) (Table 9). The average length of Eastern

Elliptio found on the surface and in excavated quadrats in 2019 (68.9 mm, SD ± 24.8) was lower (Two Sample t-Test: $p<0.02$) than Elliptio found in 2014 (73.0 mm, SD ± 35.6) and lower (Two Sample t-Test: $p < 0.001$) than the average length of Eastern Elliptio found in 2008 (93.1 mm, SD ± 8.2) (Figure 11). In 2008, we detected no juvenile Eastern Elliptio (< 40 mm) during quantitative surveys in Pine Creek. In contrast, during 2019 quantitative surveys, over 10 percent of Eastern Elliptio found were juveniles (n=99) and 30 percent of the Eastern Elliptio found in 2014 (n=134) were juveniles (Figure 11).

DISCUSSION

In 2019, we completed the final electrofishing surveys and mussel surveys of this project in both Pine Creek and Buffalo Creek. We found fewer of eels than previous surveys but higher numbers of juvenile Eastern Elliptio in both creeks than found in baseline surveys. Mussel surveys in Buffalo Creek indicate an increase in juvenile Eastern Elliptio from three found in 2010 to 18 found in 2019. There was a more significant increase in juvenile Eastern Elliptio found in Pine creek from 0 in 2008 to 134 in 2014. A high number of juveniles (99) was also found 2019. An increase in Eastern Elliptio under 70 mm resulted in the doubling of our population estimate in the 200-meter quantitative sampling site in Pine Creek from 62,432 in 2014 (SE ± 6,578) to 113,314 in 2019 (SE ± 7,049).

As expected, average length and weight of eels increased from 2014 to 2019. However, while the percent biomass of eels increased at all sites from 2014 to 2019, we captured significantly fewer eels. The steady increase in eel capture rates over time followed by a sharp decrease in 2019 suggests that eels survived and grew well near the stocking sites but are starting return to their spawning grounds in the Atlantic Ocean. It is likely that many males and possibly some females have left Buffalo and Pine Creeks to begin their downstream migration. During our PIT tag study, we identified many silver males. Male eels typically mature at an earlier age and smaller size than their female counterparts. Males start out-migrating between the ages of 6 and 15 years and achieve a total length of only 350mm, while females mature later at approximately 12 to 20 years (Oliveira 1999) and can achieve lengths up to 1,000 mm or more.

Average annual eel growth in this study (61.7 mm/year) was similar to studies conducted in South Carolina which found a maximum growth rate of 69 mm/year (Hansen and Eversole 2011) and exceeds average growth rates found in a study conducted in Maine of 30 mm/year (Oliveira and McCleave 2002). Average growth rates in Buffalo Creek are higher than those at the base of Conowingo Dam of 43 mm/year (USFWS, unpublished data). Abundant food resources likely drove higher growth rates in Buffalo Creek. As found in our PIT tag study, average growth differed by age, sex and length. One silver male that was recaptured twice grew 67 mm from 2012-2013 and only grew 30 mm from 2013-2014. As expected for silvering males, growth slows as eels prepare for downstream migration.

The increase in fish diversity in the last two years of the study was driven by lower relative abundance of several small bodied fish genera in 2014 and 2019 than 2011, 2012 and 2013. Two factors (eel CPUE (g/hr) and discharge) were correlated with these lower relative abundances. Increase in eel size (CPUE in g/hr) was negatively correlated with several smaller bodied fish genera (shiners, darters and dace). It has been documented that eels become piscivorous when they reach lengths over 400 mm (Lookabaugh and Angermeier 1992) and commonly eat smaller fish such as darters (Ogden 1970) so it is possible the decline in smaller genera is related to the increase in the size and partially piscivorous feeding habits of the eels. However, flow (i.e. discharge) was also negatively correlated. Flow during the 2014 and 2019 sampling events was high which may have allowed smaller fish to disperse making them more difficult to capture in contrast to years when flow was lower (2010, 2011 and 2012) and fish were concentrated in pools and therefore more easily captured. Additional analyses could further our understanding of the decrease in some genera of fish, including feeding studies and standardization of discharge.

The most interesting finding in 2019 was evidence of abundant numbers of Eastern Elliptio in several size classes in Pine Creek (Figure 11). The increase in the number of juveniles less than 40 mm coupled with an increase in the number of mid-length mussels (40 - 80 mm) signifies that there is now recruitment of juveniles into the Eastern Elliptio population where no juveniles were found in our initial survey in 2008. Two contributing factors may have led to this large increase in juvenile Eastern Elliptio in Pine Creek. First, the location with the highest CPUE of Eastern Elliptio surveyed to date in the Susquehanna River watershed (701 mussels/hr in 2014) is approximately 400 m downstream of the sample site. This CPUE is similar to CPUE of Eastern Elliptio found in the Delaware River where it is common to find > 500 Eastern Elliptio/hr (Blakeslee et al. 2018). This high density of Eastern Elliptio likely produces a large number of freshwater mussel larvae each spring. The second factor is the location of this site between two of the Pine Creek eel stocking sites: Darling Run is approximately 200 m downstream and Ansonia Bridge is approximately 1000 m upstream of the mussel survey site. The large number of larvae available coupled with presence of eels stocked upstream and downstream, likely contributed to the increase in recruitment of juvenile Eastern Elliptio.

While there was a small increase in Eastern Elliptio juveniles in Buffalo Creek from 2010 to 2019, the increase was less than observed in Pine Creek. The two creeks are different in several ways that may have influenced recruitment of juvenile Eastern Elliptio. Buffalo Creek had a lower water quality index (49.3) than Pine Creek (66.2) according to the Susquehanna

River Basin Commission (pers. Comm. Luanne Steffy) (Figure 12). Both watersheds are less than 1% urban but the upstream drainage area of Pine Creek is 89% forest cover while Buffalo Creek's upstream drainage area is only 58% forest cover due to more agriculture. Landscapes that have been highly altered by agriculture have higher soil erosion, stream bank erosion and increased nutrients that can have negative effects on mussel communities (Brim Box and Mossa 1999) including the disruption of multiple steps in reproduction (Gascho Landis and Stoeckel 2016). It has been documented that agriculture is associated with low growth and survival of juvenile mussels (Haag et al. 2019). Our results indicate that reintroducing eels alone may not be enough to greatly increase Eastern Elliptio juvenile recruitment and abundance in streams where there is a history of poor water quality or increased sediment due to agriculture.

CONCLUSIONS

The results of the 2019 quantitative mussel surveys provide additional evidence that American eels may be a limiting factor in Eastern Elliptio recruitment and that eel reintroductions can lead to Eastern Elliptio population increases. However, it appears that water quality can be a factor influencing Eastern Elliptio recruitment and subsequent growth rates of Eastern Elliptio populations. Also, because the life cycle of American Eels demands that they outmigrate to the Sargasso Sea to spawn, unless their populations are adequately replaced, we are likely to see a drop in Eastern Elliptio recruitment in Buffalo and Pine Creeks. Future efforts will be focused on implementing plans to trap eels at Conowingo Dam and transport them above the 4 mainstem dams where eels can continue their upstream migration to suitable habitat.

An increase in American Eel distribution across the watershed would increase the possibility of Eastern Elliptio recruitment in many watersheds. However, if targeted mussel restoration in the Susquehanna River watershed is a goal, each tributary should be assessed for juvenile survival and growth. It would be useful to evaluate habitat suitability for mussel reintroduction by placing either caged juveniles or caged adults in tributaries to assess growth and survival before starting targeted restoration projects (Gray and Kreeger 2013 and Kyle et al. 2016).

Our results suggest that eel trap and transport or permanent eel passage at the 4-mainstem Susquehanna River dams would likely improve ecological function in the watershed by increasing recruitment of Eastern Elliptio in streams with adequate water quality. The presence of healthy freshwater mussel beds provides streambed stability, water filtration, and increased macroinvertebrate biodiversity.

ACKNOWLEDGEMENTS

Thank you to the many people who contributed long hours of, among other things, backpack shocking, snorkeling, mussel grubbing, and equipment lugging to this project including J. Barton, C. Blakeslee, J. Brown, K. Bullock, J. Cole, C. Conover, J. Gill, G. Goodenowe, S. Eyler, A. Horne, W. Kung, B. Lellis, M. Magliocca, M. Mangold, N. Mee, I. Park, S. Reese, M. Rinehimer, R. Schlitt, P. Shellenberger, J. Siani, D. Spooner, W. B. St. John White, M. Turner, and K. Whiteford as well as many field crews too numerous to mention.

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Table 1. Eels stocked in Buffalo Creek (Union County, PA), Pine Creek (Tioga County, PA) and Conowingo Creek (Lancaster County, PA) in 2010, 2011, 2012, and 2013.

Date	# Stocked	Location	Mean Length (mm)	Origin
		Pine Creek		
June 9, 2010	3,000	Darling Run Access	56.3*	Turville Creek
June 9, 2010	3,000	Ansonia Bridge	56.3*	Turville Creek
June 9, 2010	3,000	Owassee Rapids	56.3*	Turville Creek
June 21, 2011	10,666	Darling Run Access	80.1 ± 16.0	Turville Creek
June 21, 2011	10,666	Ansonia Bridge	80.1 ± 16.0	Turville Creek
June 21, 2011	10,668	Owassee Rapids	80.1 ± 16.0	Turville Creek
June 30, 2011	7,222	Marsh Creek Boat Ramp	127 ± 16.9	Conowingo Dam
August 22, 2011	1,528	Ansonia Bridge	127 ± 16.9	Conowingo Dam
August 31, 2011	8,940	Ansonia Bridge	127 ± 16.9	Conowingo Dam
September 2, 2011	8,084	Ansonia Bridge	127 ± 16.9	Conowingo Dam
September 7, 2011	12,205	Ansonia Bridge	127 ± 16.9	Conowingo Dam
May 24, 2012	15,237	Darling Run Access	67.4 ± 10.0	Bishopville Prong
June 6, 2012	16,241	Ansonia Bridge	121.0 ±16.5	Conowingo Dam
June 20, 2012	11,592	Ansonia Bridge	121.0 ±16.5	Conowingo Dam
Total	**122,049**			
		Buffalo Creek		
June 10, 2010	8,084	Strawbridge Rd. Bridge	127.7	Conowingo Dam
June 10, 2010	4,500	Strawbridge Rd. Bridge	56.3*	Turville Creek
June 10, 2010	4,500	Footbridge on Rt. 1003	56.3*	Turville Creek
June 21, 2010	7,790	Strawbridge Rd. Bridge	127.7	Conowingo Dam
June 21, 2011	16,219	Strawbridge Rd. Bridge	80.1 ± 16.0	Turville Creek
June 21, 2011	16,000	Footbridge on Rt. 1003	80.1 ± 16.0	Turville Creek
July 14, 2011	6,326	Strawbridge Rd. Bridge	127 ± 16.9	Conowingo Dam
July 18, 2011	4,390	Strawbridge Rd. Bridge	127 ± 16.9	Conowingo Dam
July 28, 2011	3,603	Strawbridge Rd. Bridge	127 ± 16.9	Conowingo Dam
May 24, 2012	8,526	Strawbridge Rd. Bridge	67.4 ± 10.0	Bishopville Prong
May 31, 2012	7,122	Strawbridge Rd. Bridge	121.0 ±16.5	Conowingo Dam
August 7, 2012	1,068	Strawbridge Rd. Bridge	121.0 ±16.5	Conowingo Dam
June 26, 2013	7,908	Strawbridge Rd. Bridge	127 ± 16.9	Conowingo Dam
August 22, 2013	22,706	Penetentiary	127 ± 16.9	Conowingo Dam
Total	**118,742**			

* length (mm) of glass eels was estimated using regression

Table 2. Number and catch per unit effort (CPUE, #/hour) of fish species captured in Buffalo Creek and Pine Creek during electrofishing surveys conducted in July of 2019.

	Buffalo Creek				**Pine Creek**			
	Strawbridge Rd Bridge		Footbridge on Rt 1003		Darling Run Access		Ansonia Bridge	
Shock time (hours)	3.113		3.797		2.948		3.168	
Common name	#	CPUE	#	CPUE	#	CPUE	#	CPUE
American Eel	8	2.6	8	2.1	14	4.7	15	4.7
Creek Chubsucker	2	0.6	16	4.2	1	0.3	0	0.0
Northern Hogsucker	9	2.9	6	1.6	49	16.6	12	3.8
White Sucker	7	2.2	20	5.3	58	19.7	9	2.8
Rockbass	6	1.9	18	4.7	2	0.7	0	0.0
Redbreast Sunfish	5	1.6	34	9.0	3	1.0	0	0.0
Green Sunfish	27	8.7	8	2.1	0	0.0	0	0.0
Pumpkinseed	0	0.0	3	0.8	0	0.0	0	0.0
Bluegill	1	0.3	4	1.1	0	0.0	0	0.0
Smallmouth Bass	4	1.3	12	3.2	6	2.0	9	2.8
Central Stoneroller	0	0.0	0	0.0	3	1.0	1	0.3
Spotfin Shiner	1	0.3	0	0.0	0	0.0	0	0.0
Cutlips Minnow	46	14.8	4	1.1	28	9.5	81	25.6
Common Shiner	1	0.3	1	0.3	8	2.7	1	0.3
Pearl Dace	0	0.0	0	0.0	0	0.0	1	0.3
River Chub	0	0.0	0	0.0	15	5.1	192	60.6
Spottail Shiner	0	0.0	0	0.0	9	3.1	0	0.0
Rosyface Shiner	39	12.5	6	1.6	7	2.4	2	0.6
Mimic Shiner	51	16.4	1	0.3	5	1.7	0	0.0
Bluntnose Minnow	2	0.6	0	0.0	1	0.3	0	0.0
Blacknose Dace	1	0.3	0	0.0	0	0.0	7	2.2
Longnose Dace	20	6.4	0	0.0	0	0.0	46	14.5
Creek Chub	2	0.6	16	4.2	1	0.3	0	0.0
Fallfish	19	6.1	24	6.3	12	4.1	2	0.6
Yellow Bullhead	0	0.0	3	0.8	0	0.0	0	0.0
Margined Madtom	71	22.8	9	2.4	16	5.4	149	47.0
Greenside Darter	53	17.0	12	3.2	24	8.1	20	6.3
Tessellated Darter	40	12.8	88	23.2	110	37.3	138	43.6
Banded Darter	16	5.1	17	4.5	5	1.7	88	27.8
Shield Darter	40	12.8	57	15.0	16	5.4	34	10.7

Table 3. Density (# eels/m^2) of eels, estimated abundance (Seber and Le Cren 1967) (± S.E.) of eels in a 75 meter length of stream, average length (± S.D.) and % biomass of captured fish that were eels during 2011, 2012, 2014 and 2019 electrofishing surveys in Buffalo Creek and Pine Creek. We could not estimate abundance at the Footbridge in Buffalo Creek in 2011 and 2019 and Ansonia Bridge in 2011 because the number of eels captured in the first pass did not exceed the second pass

2011

	Buffalo Creek		**Pine Creek**	
	Strawbridge Rd Bridge	Footbridge on Rt 1003	Darling Run Access	Ansonia Bridge
Density (# eels/m^2)	0.17	n/a	0.004	n/a
Abundance	480.3 (± 14)	n/a	12.5 (± 1)	n/a
Ave. Length (mm)	137 (± 24)	193 (± 21)	161 (± 37)	118 (± 28)
% Biomass	10.1	6.1	1.2	0.6

2012

	Buffalo Creek		**Pine Creek**	
	Strawbridge Rd Bridge	Footbridge on Rt 1003	Darling Run Access	Ansonia Bridge
Density (# eels/m^2)	0.03	0.04	0.008	0.07
Abundance	72 (± 6)	160 (± 41)	28 (± 9)	302 (± 37)
Ave. Length (mm)	154 (± 41)	223 (± 68)	167 (± 46)	124 (± 26)
% Biomass	3.8	9	2.7	4.8

2014

	Buffalo Creek		**Pine Creek**	
	Strawbridge Rd Bridge	Footbridge on Rte. 1003	Darling Run Access	Ansonia Bridge
Density (# eels/m^2)	0.03	0.05	0.03	0.02
Abundance	62 (± 6)	131 (± 13)	65 (± 85)	54 (± 21)
Ave. Length (mm)	215 (± 58)	236 (± 65)	262 (± 67)	272 (± 58)
% Biomass	21.1	10.2	29.2	52.8

2019

	Buffalo Creek		**Pine Creek**	
	Strawbridge Rd Bridge	Footbridge on Rte. 1003	Darling Run Access	Ansonia Bridge
Density (# eels/m^2)	0.004	n/a	0.006	0.007
Abundance	9 (± 2)	n/a	14 (± 0.9)	16 (± 1.7)
Ave. Length (mm)	430 (± 90)	432 (± 86)	414 (± 77)	433 (± 86)
% Biomass	20.7	9.3	42.4	46.6

Table 4. Shannon-Wiener Diversity index by genus for fish captured in Pine Creek and Buffalo Creek from 2010 to 2019.

Shannon Diversity Index	2010	2011	2012	2014	2019
Buffalo Creek	1.78	1.64	2.03	2.44	2.33
Pine Creek	1.88	1.94	2.24	2.20	2.12

Table 5. Spearman Correlation coefficients calculated for Eel CPUE (g/hr) and Discharge ((from USGS 01548500 Pine Creek at Cedar Run, PA and the surrogate for Buffalo Creek, USGS 01555000 Penns Creek at Penns Creek, PA) for the most CPUE (#/hr) of the common genera in Buffalo and Pine Creek from 2010 to 2019. Negative correlation ≤ - 0.05 is shaded in red, positive correlation ≥ 0.05 is shaded green.

	Buffalo		**Pine**	
	Eel CPUE	**Discharge**	**Eel CPUE**	**Discharge**
Catastomas (White Sucker)	-0.9	-0.6	0.3	0.3
Etheostoma (Darter sp.)	-0.8	-0.7	-0.5	-0.5
Exoglossum (Cutlips Minnow)	0	0.4	0.2	0.2
Lepomis (Sunfish sp.)	0.7	0.2	-0.3	-0.3
Micropterus (Smallmouth Bass)	0.1	-0.5	0.2	0.2
Hypentelium (Northern Hogsucker)	-0.8	0.0	0.4	0.4
Notropis (Shiner sp.)	-0.9	0.1	-0.7	-0.7
Noturus (Margined Madtom)	-0.6	0.1	-0.2	-0.2
Percina (Shield Darter)	0.1	-0.6	-0.9	-0.9
Rhinichthys (Dace sp.)	-0.6	-0.1	-0.7	-0.7
Semotilus (Fallfish)	-0.1	0	-0.6	-0.6

Table 6. Yearly catch, effort, and relative abundance data (catch-per-unit effort; CPUE, eels/hr) for eels captured at two sites in Buffalo Creek during the PIT tag study.

YEAR	**EELS CAUGHT**	**CPUE**
2012	233	34.8
2013	295	44.4
2014	313	57.5
2015	432	64.6
2016	457	54.1
2017	515	55.5
2018	217	29.8
2019	141	19.8

Table 7. Yearly number of releases and recaptures for eels tagged at two sites in Buffalo Creek from 2012-2019. Yearly recapture rate (%) is the number of recaptures for a given release year.

Release Year	Tags Released	Recapture Year							Release Year Recapture Rate
		2013	2014	2015	2016	2017	2018	2019	
2012	174	11	6	4	3	2	2	3	17.8
2013	168		6	6	3	3	3		12.5
2014	171			11	9	4		1	14.0
2015	320				31	21	4	2	18.1
2016	324					42	13	11	20.4
2017	434						32	17	11.3
2018	164							13	7.9

Table 8. Total catch and catch-per-unit effort (CPUE; fish/hr) of American Eel from upper watershed sites in Buffalo Creek from 2017-2019. Note no eels have been captured at sites 1 or 10 and those sites are not listed below.

Sample Site	2017		2018		2019	
	Catch	CPUE	Catch	CPUE	Catch	CPUE
2	--	--	1	1.5	1	2.4
3	5	8.2	2	3.1	4	5.7
4	3	9.3	--	--	1	3.4
5	2	3.2	8	11.9	8	14.0
6	1	3.1	--	--	--	--
7	1	1.5	--	--	1	1.5
8	3	3.0	3	4.3	4	5.1
9	1	1.6	--	--	--	--
11	1	1.7	1	5.1	2	5.7
12	5	6.8	2	2.9	3	4.1

Table 9. Relative abundance (%), density (in individuals/m^2, ± SE and 90% Confidence), and population abundance (± SE and 90% Confidence), estimated using the Mussel Estimation Program (Smith 2007), of mussels found during quantitative surveys below the footbridge at Rt 1003 in Buffalo Creek and at Darling Run in Pine Creek.

Species	**Relative Abund.**	**Density Est.**	**SE**	**90% CL**	**Abund. Est.**	**SE**	**90% CL**
Pine Creek							
2008							
ALL		6.12	0.64	5.15-7.28	62,432	6578	52,497-74,246
Brook Floater	0.44	0.02	0.02	0.01-0.09	275	198	84-899
Eastern Elliptio	97.09	5.94	0.64	4.97-7.10	60,615	6568	50,720-72,440
Creeper	2.48	0.15	0.04	0.09-0.25	1546	457	951-2513
2014							
ALL		5.43	0.26	5.03-5.87	33,050	1556	30,586-35,711
Brook Floater	9.23	0.50	0.10	0.36-0.70	3050	616	2188-4251
Eastern Elliptio	85.5	4.65	0.18	4.35-5.00	28,257	1114	26,483-30,150
Green Floater	1.32	0.07	0.02	0.04-0.13	436	149	249-764
Creeper	3.95	0.22	0.03	0.17-0.28	1307	208	1005-1699
2019							
ALL		11.08	0.69	10.01-12.28	113,314	7049	102,291-125,524
Elktoe	0.09	0.01	0.01	0.00-0.05	103	103	20-529
Brook Floater	12.18	1.35	0.14	1.13-1.61	13,804	1478	11,574-16,463
Eastern Elliptio	86.63	9.57	0.66	8.55-10.71	97,862	6722	87,407-109,568
Creeper	1.36	0.15	0.02	0.12-0.19	1545	210	1236-1932
Buffalo Creek							
2010							
ALL		5.44	0.37	4.86-6.10	28,788	1981	25,708-32,238
Eastern Elliptio	94.65	5.15	0.35	4.61-5.75	27,249	1831	24,397-30,434
Creeper	5.35	0.29	0.03	0.24-0.35	1539	171	1282-1848
2014							
ALL		5.59	0.41	4.95-6.31	26,775	1985	23,701-30,247
Eastern Elliptio	97.53	5.45	0.44	4.78-6.22	26,114	2091	22,891-29,789
Creeper	2.16	0.12	0.03	0.08-0.19	578	157	370-905
Rainbow	0.31	0.02	0.02	0.00-0.09	83	82	16-424
2019							
ALL		4.69	0.61	3.78-5.81	27,550	3594	22,230-34,143
Eastern Elliptio	99.70	4.67	0.62	3.78-5.81	27,467	3648	22,077-34,173
Green Floater	0.3	0.01	0.01	0.01-0.07	82	82	16-423

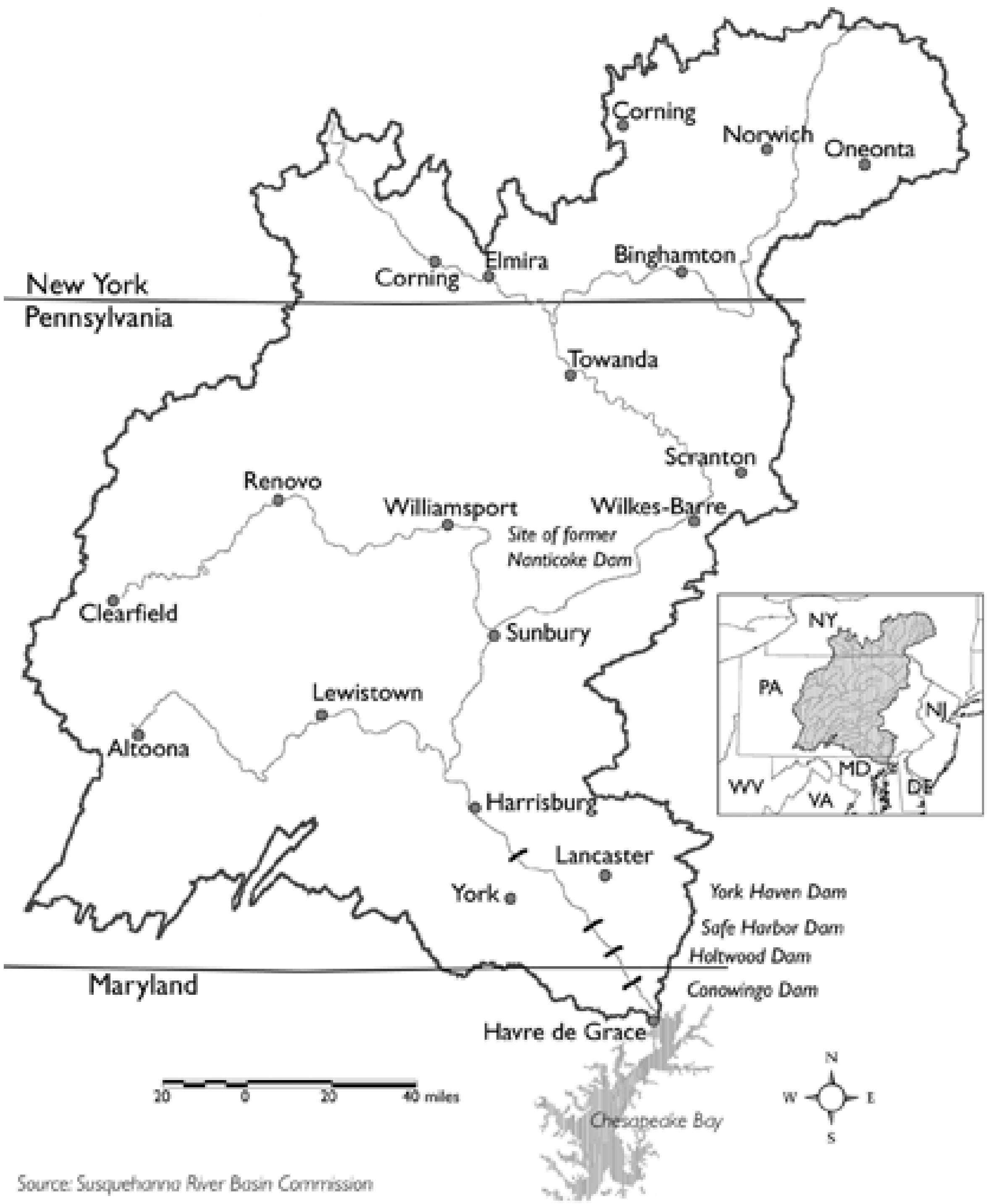


Figure 1. Susquehanna River watershed with the locations of the 4 hydroelectric dams, York Haven, Safe Harbor, Holtwood, and Conowingo denoted by straight lines across the mainstem Susquehanna River.

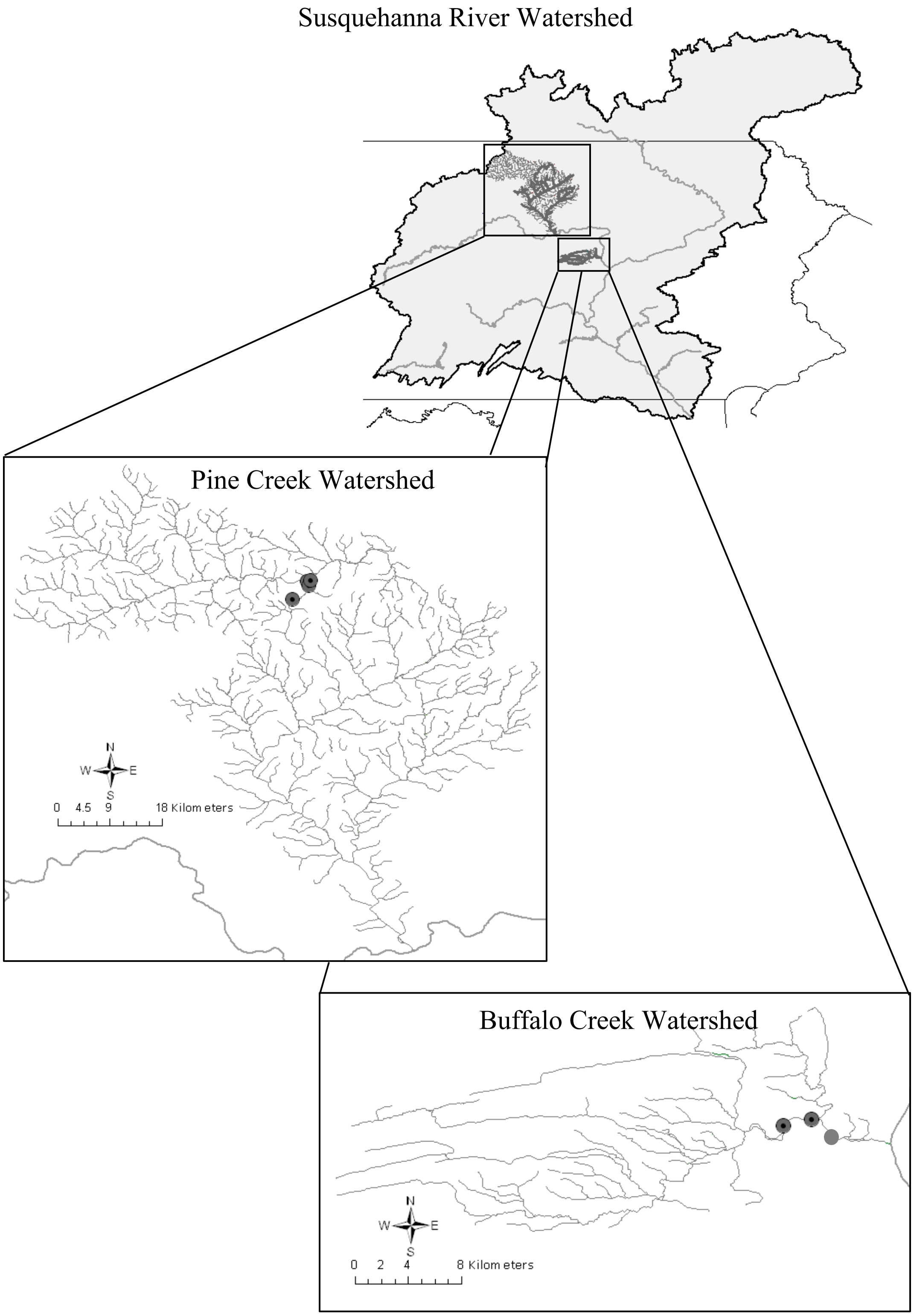


Figure 2. Eel stocking sites (indicated by dots) at Owassee Rapids, Darling Run Access, Marsh Creek, and Ansonia Bridge in Pine Creek (Tioga County, PA) and Strawbridge Rd. Bridge and the footbridge at Rt. 1003 in Buffalo Creek (Union County, PA) in the Susquehanna River drainage.

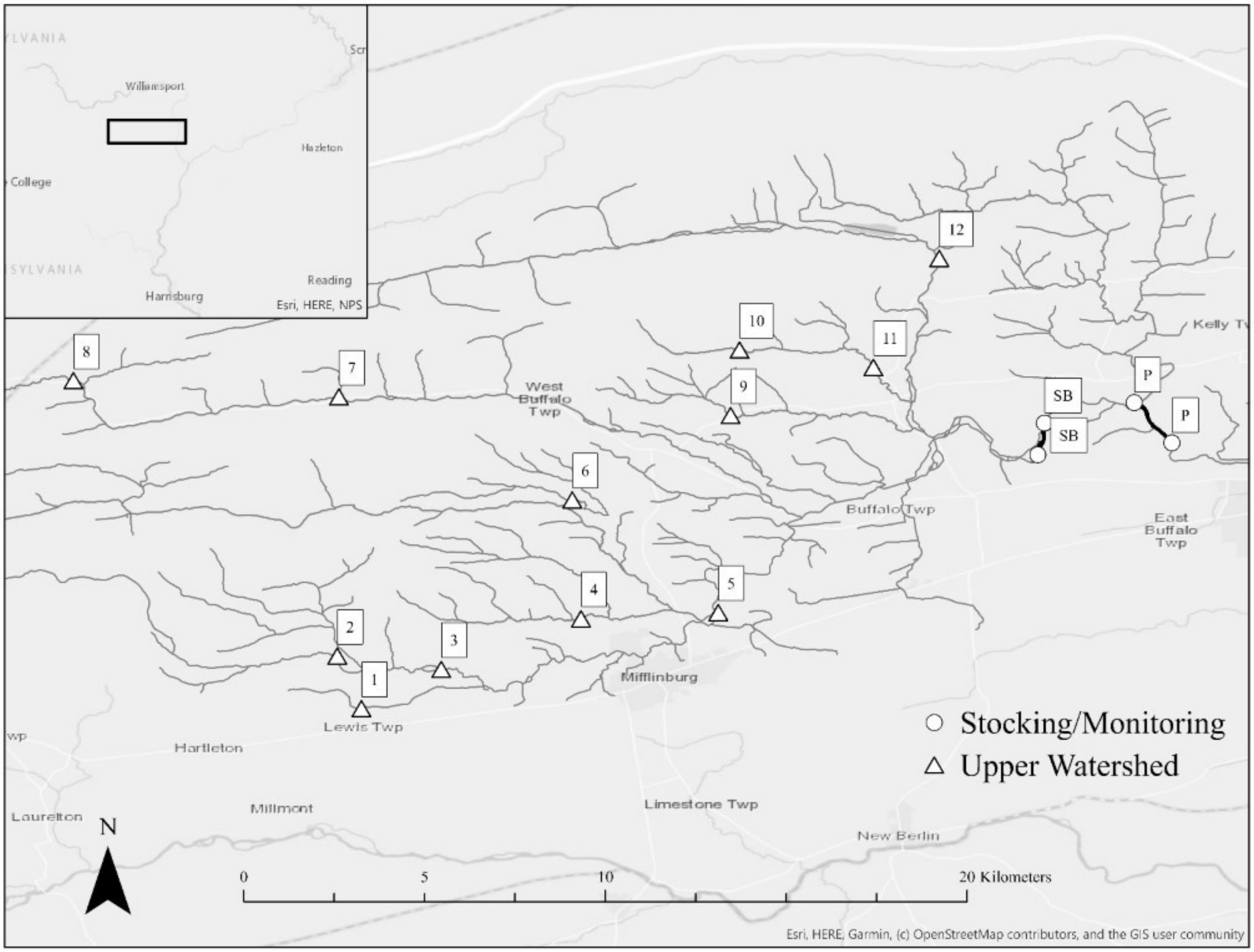


Figure 3. Map of all locations sampled in Buffalo Creek from 2012-2019 (stocking/monitoring sites; open circles) and 2017-2019 (upper watershed sites; open triangles). Dark lines mark approximate area sampled for Prison (P) and Swinging Bridge (SB) sites. Black rectangle in inset map denotes area of Buffalo Creek along Susquehanna River

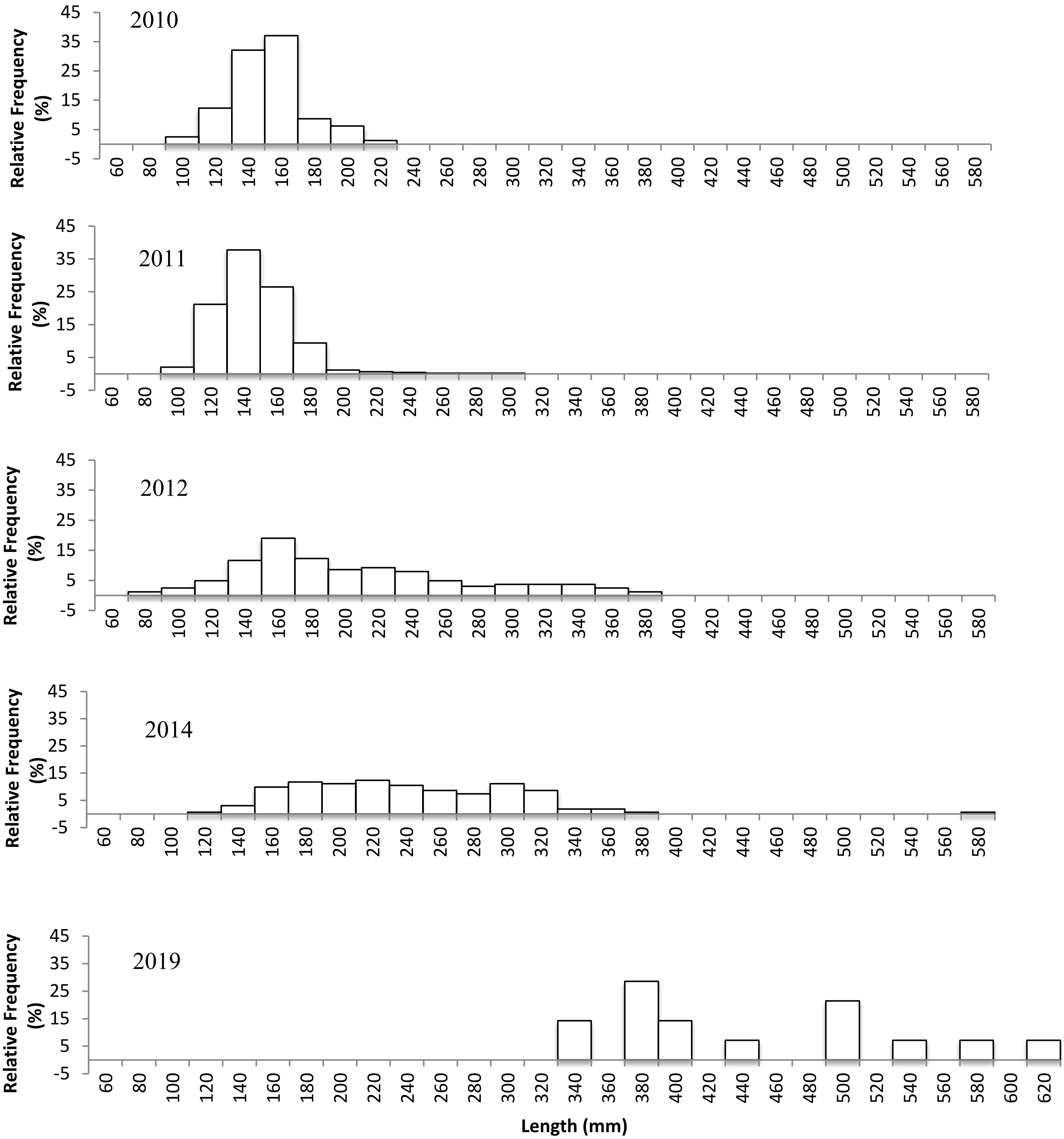


Figure 4. Relative length frequency (expressed as percentage in each length range) of eels captured during monitoring surveys in Buffalo Creek in 2010 (n = 81), 2011 (n = 434), 2012 (n = 163), 2014 (n = 162) and 2019 (n = 16)

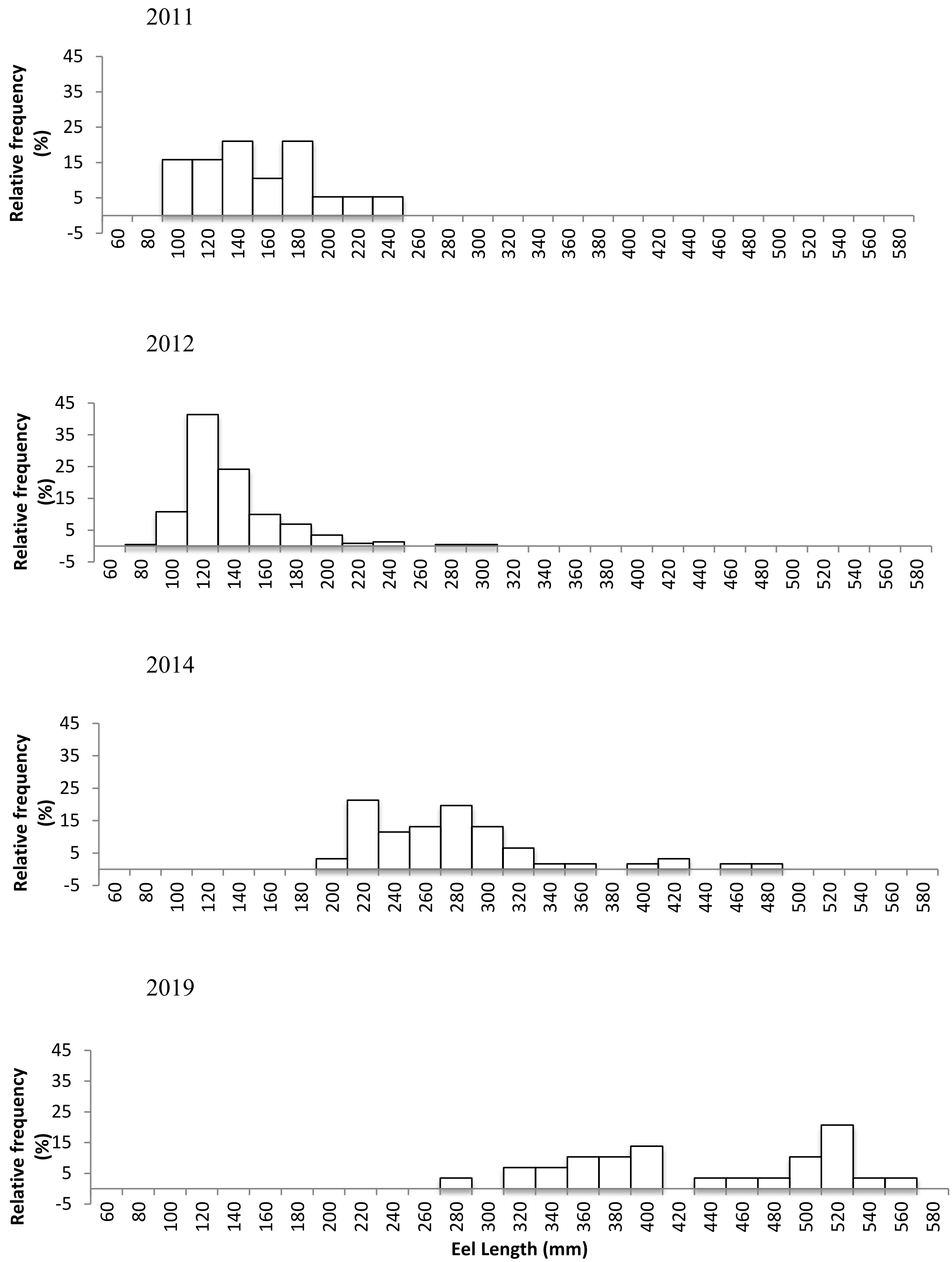


Figure 5. Relative length frequency (expressed as percentage in each length range) of eels captured during monitoring surveys in Pine Creek in 2011(n = 20), 2012 (n = 232), 2014 (n = 61) and 2019 (n = 29)

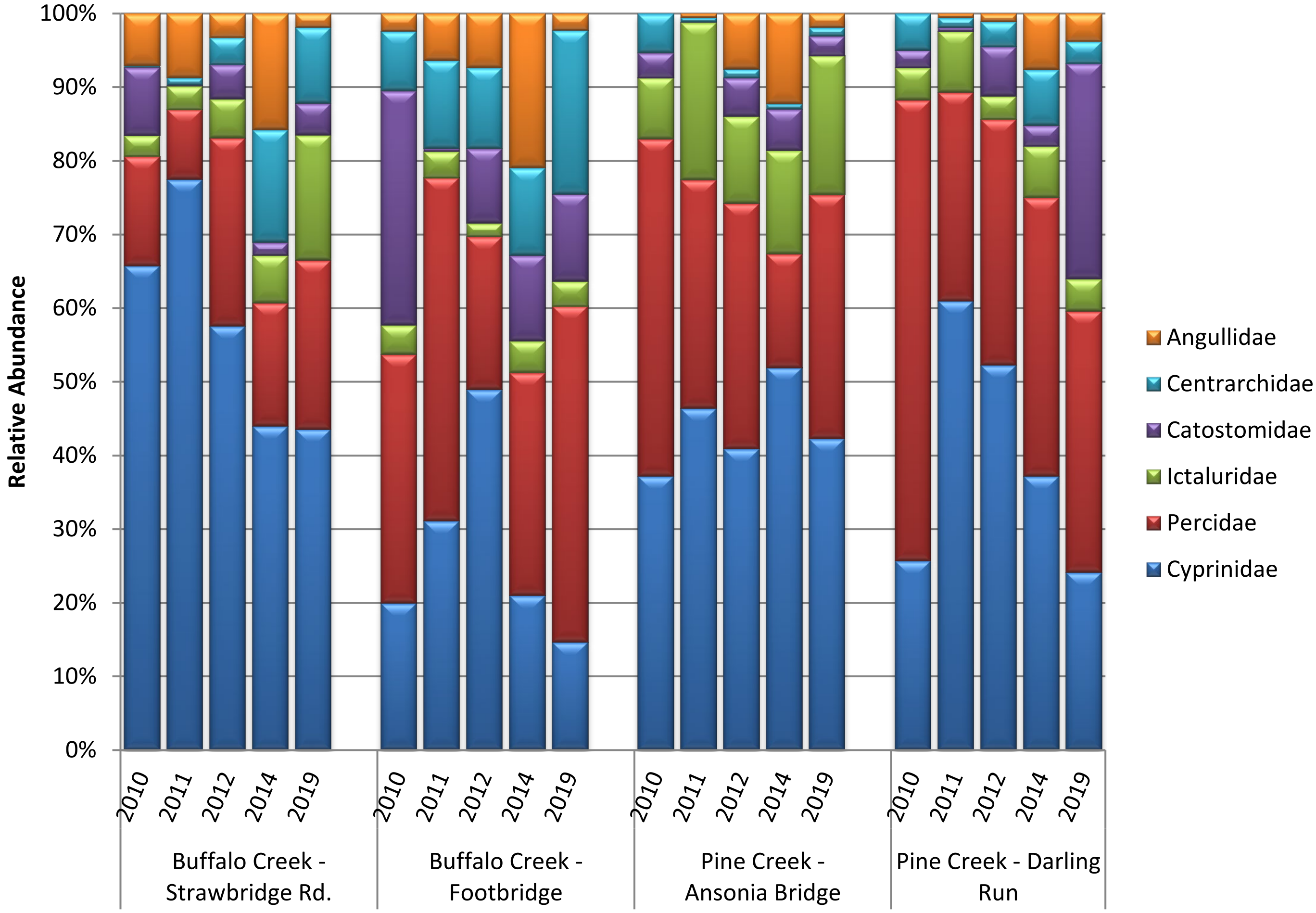
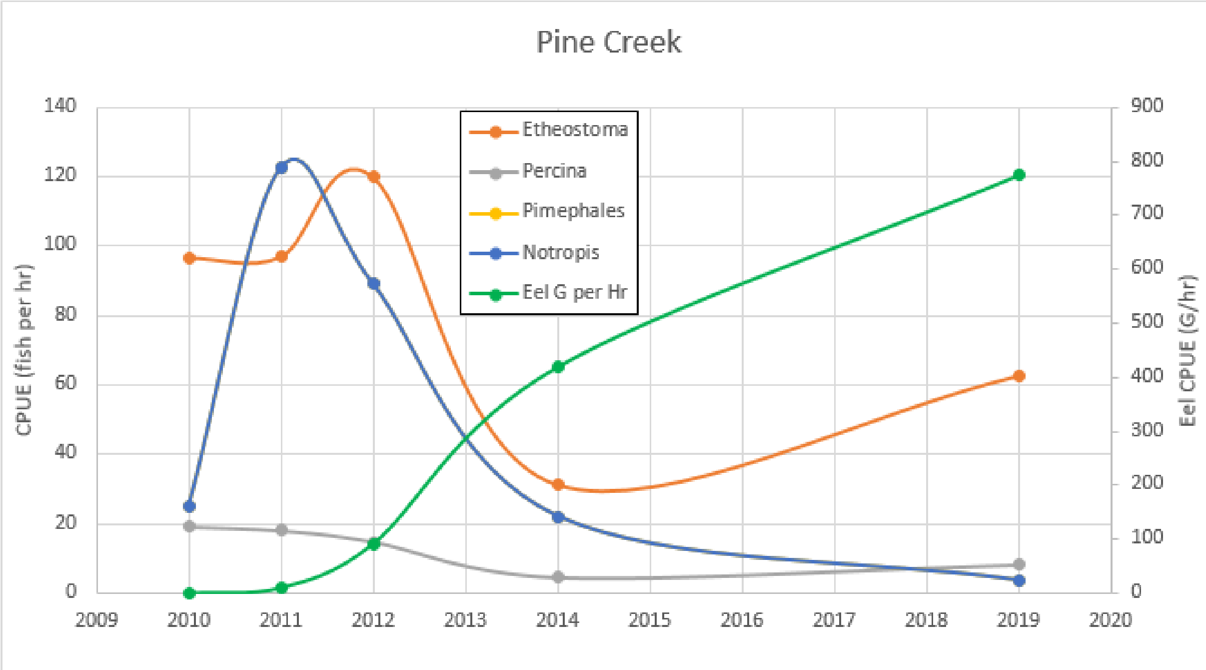


Figure 6. Relative abundance expressed as a percentage of 6 families of fish, Anguillidae (eels), Centrarchidae (sunfish and bass), Catastomidae (suckers), Ictaluridae (catfish and madtoms), Percidae (perch and darters), and Cyprinidae (minnows and shiners), caught in Buffalo and Pine Creeks during backpack electrofishing in July and August, 2010, 2011, 2012, 2014 and 2019.



Buffalo Creek

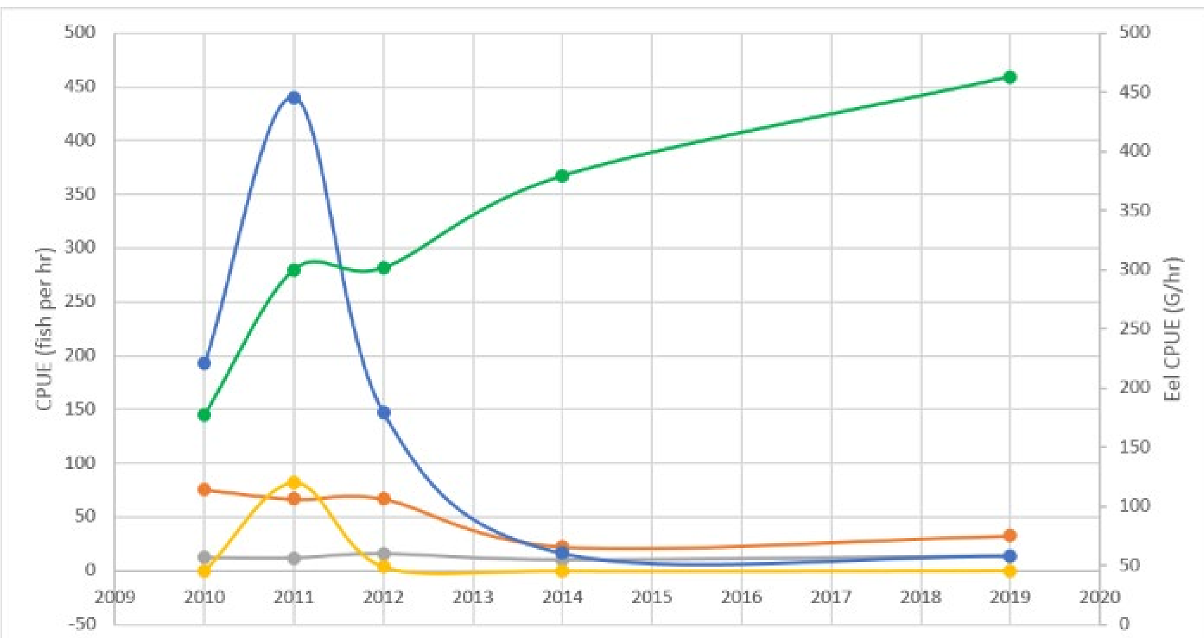


Figure 7. Relative abundance of eel catch in grams per unit effort (CPUE grams per hour) and 4 genus, *Ethostoma, Percina, Pimephales,* and *Notropis* catch in number of fish per hour (CPUE fish per hour) in Pine Creek and Buffalo Creek.

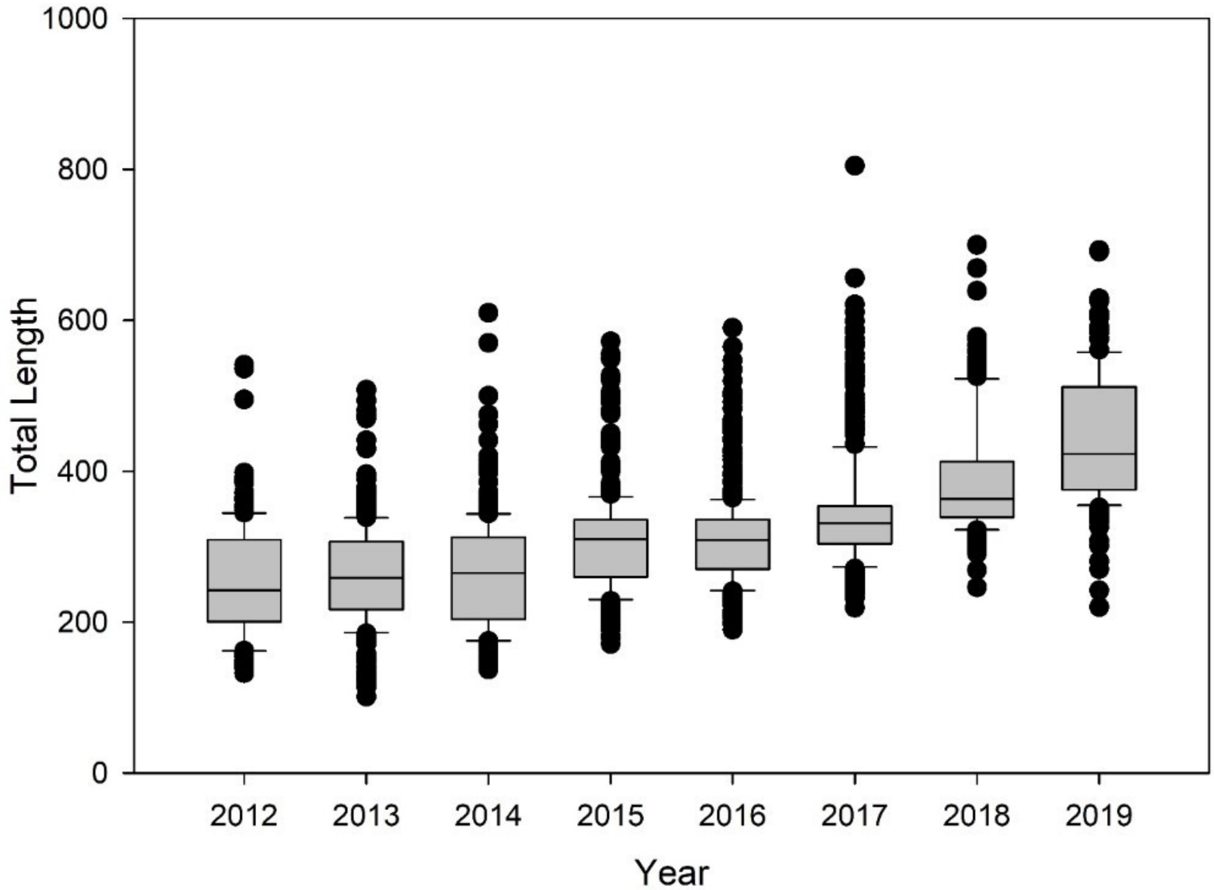


Figure 8. Box plot of total lengths of all eels captured near stocking locations in Buffalo Creek from 2012-2019. Line inside box represents median total length (mm), while the lower and upper bounds of the box represent the 25th and 75th percentiles, respectively. Bars represent the 90th and 10th percentiles.

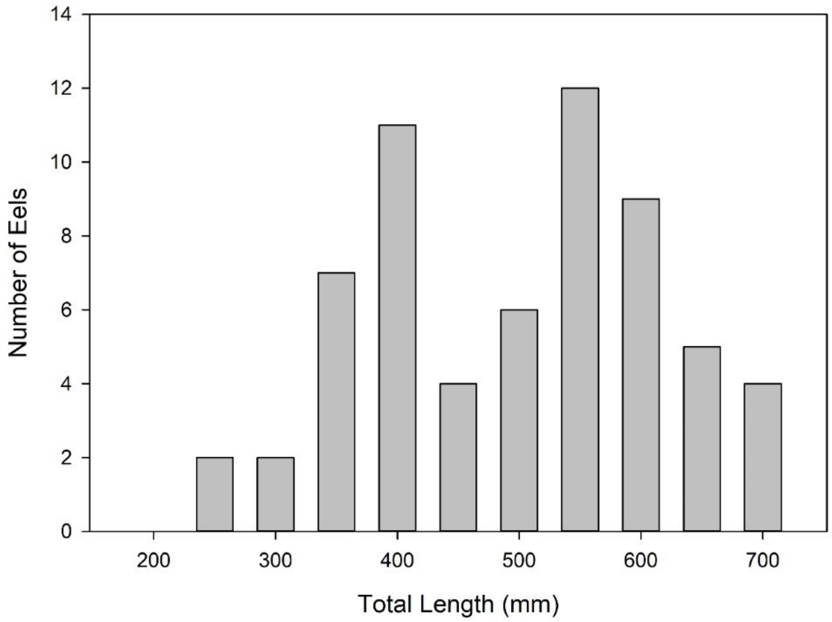


Figure 9. Length-frequency histogram for all eels captured at upper watershed Buffalo Creek sites from 2017-2019.

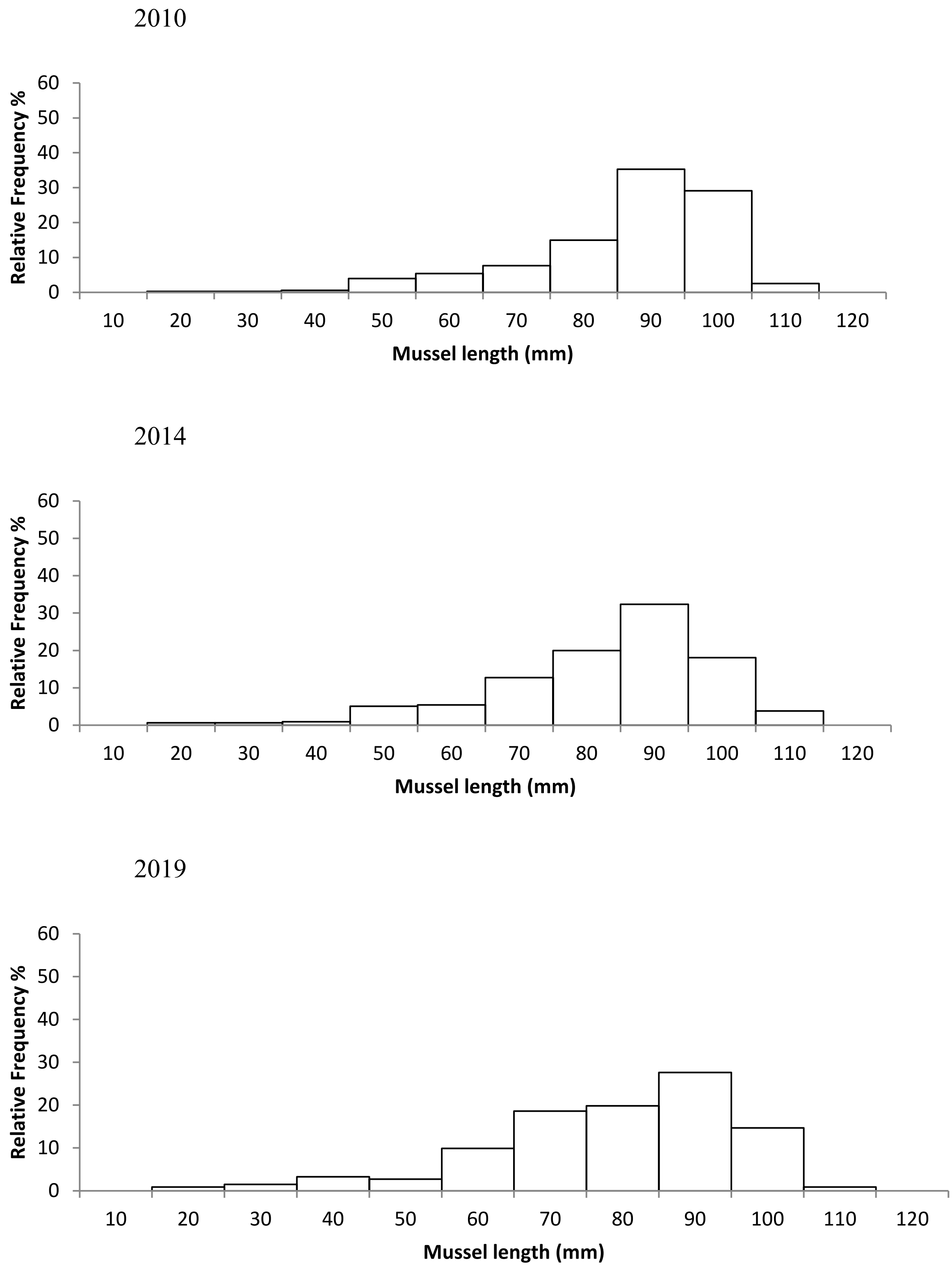


Figure 10. Relative length frequency (%) of Eastern Elliptio found during the quantitative surveys in Buffalo Creek in 2010 (n = 354), 2014 (n = 315) and 2019 (n = 333).

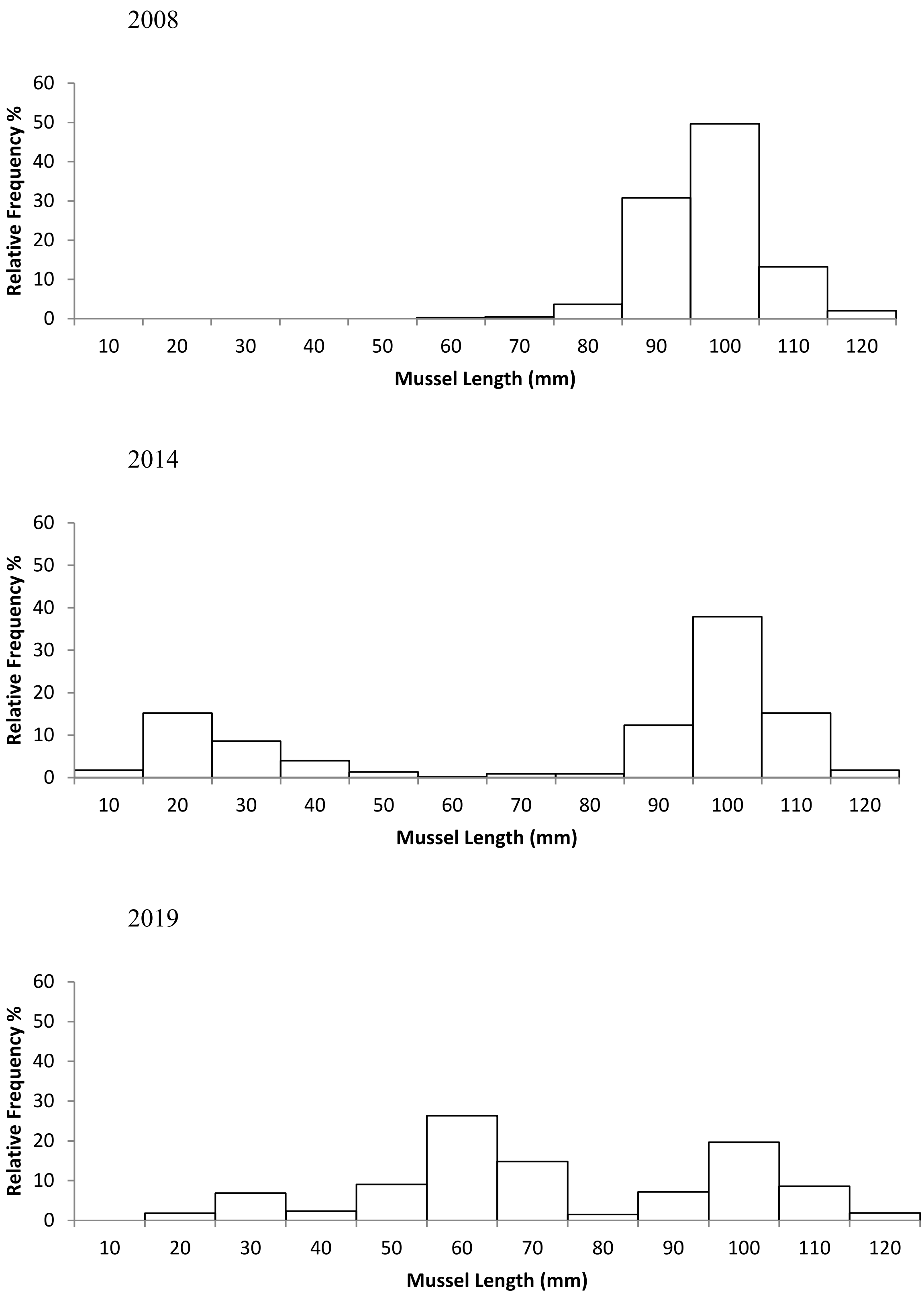


Figure 11. Relative length frequency (%) of Eastern Elliptio found during the quantitative surveys in Pine Creek in 2010 (n = 439), 2014 (n = 454), and 2019 (n=950)

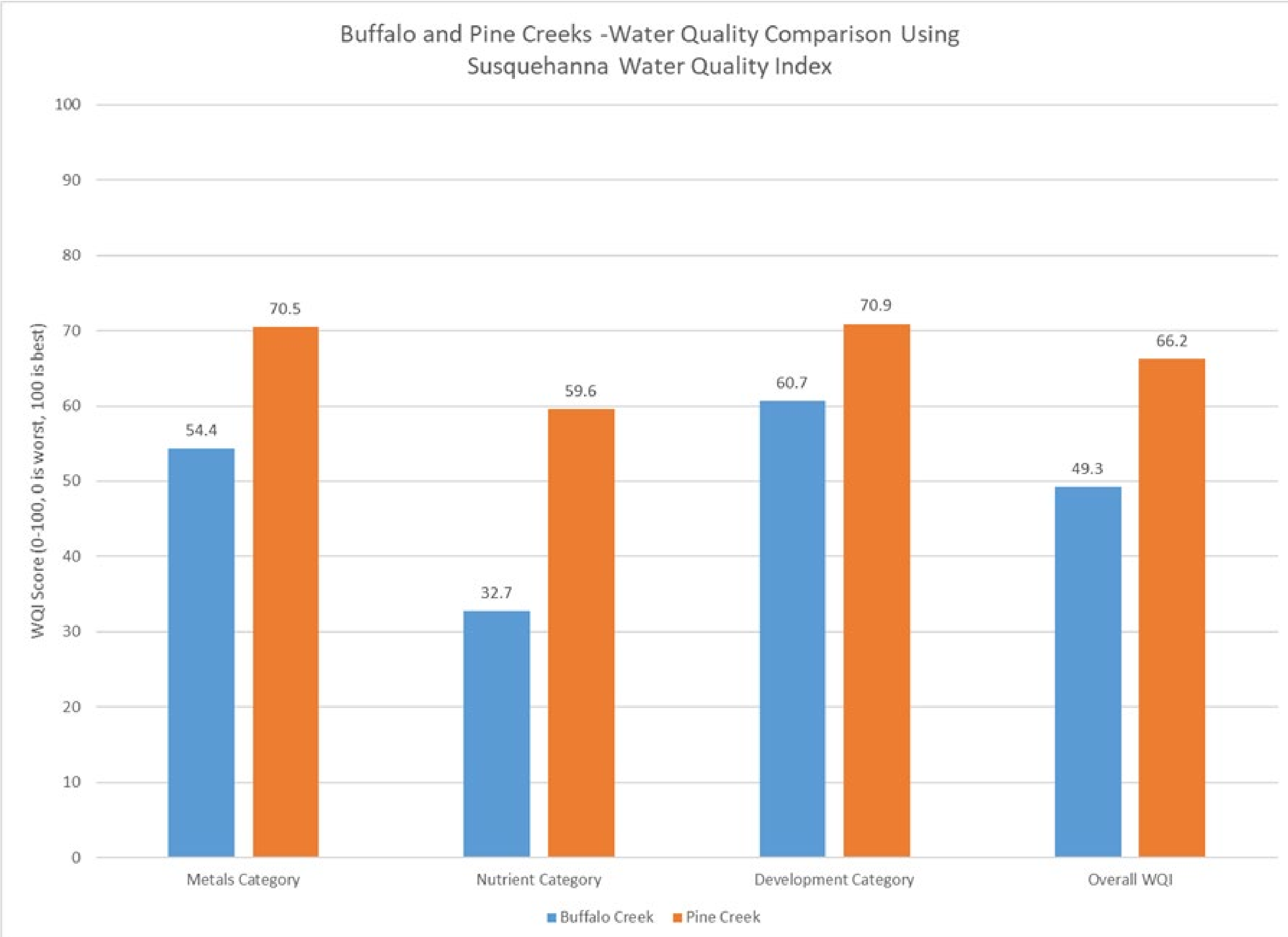
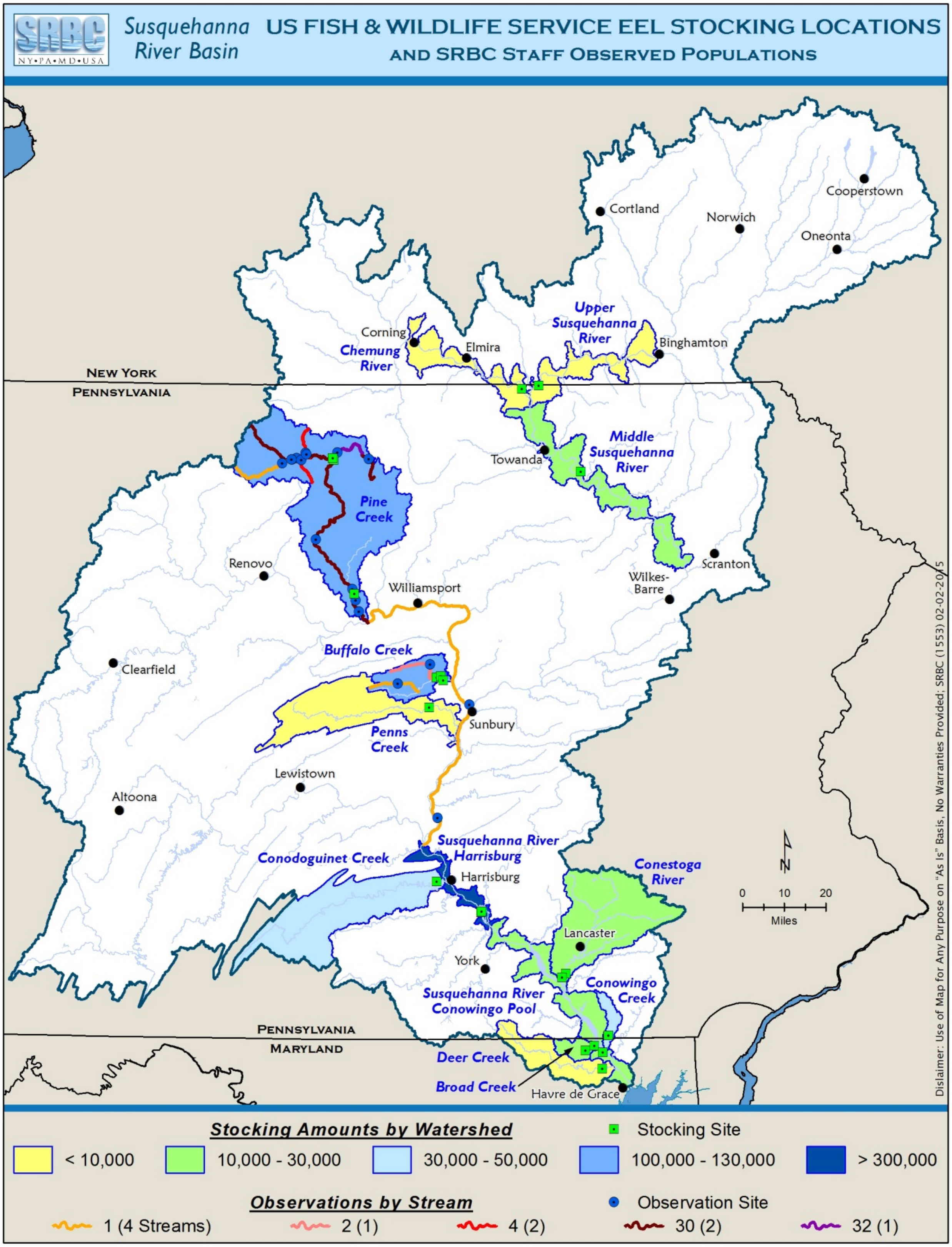


Figure 12. Susquehanna River Watershed WQI, developed by the Susquehanna River Basin Commission, for Buffalo Creek and Pine Creek including categories for Metals, Nutrients Development and Overall Water Quality.



Appendix 1. American eel stocking and recapture locations in the Susquehanna River Watershed from 2008 to 2014. Map courtesy of the Susquehanna River Basin Commission (Henning et al. 2015)

Appendix 2. Number and catch per unit effort (CPUE, #/hour) of fish species captured in Buffalo Creek and Pine Creek during electrofishing surveys conducted in July of 2014.

	Buffalo Creek				**Pine Creek**			
	Strawbridge Rd Bridge		Footbridge on Rt 1003		Darling Run Access		Ansonia Bridge	
Shock time (hours)	3.5		4.2		3.1		2.4	
Common name	#	CPUE	#	CPUE	#	CPUE	#	CPUE
American Eel	54	15.3	108	25.9	25	7.9	35	14.3
Creek Chubsucker	0	0.0	0	0.0	0	0.0	9	3.7
Northern Hogsucker	4	1.1	8	1.9	4	1.3	2	0.8
White Sucker	2	0.6	52	12.5	5	1.6	5	2.0
Rockbass	27	7.7	20	4.8	7	2.2	1	0.4
Redbreast Sunfish	12	3.4	5	1.2	12	3.8	0	0.0
Green Sunfish	1	0.3	0	0.0	0	0.0	0	0.0
Pumpkinseed	0	0.0	2	0.5	0	0.0	0	0.0
Bluegill	3	0.9	4	1.0	0	0.0	0	0.0
Smallmouth Bass	9	2.6	30	7.2	6	1.9	1	0.4
Mottled Sculpin	0	0.0	2	0.5	0	0.0	0	0.0
Central Stoneroller	2	0.6	0	0.0	1	0.3	5	2.0
Cutlips Minnow	15	4.3	18	4.3	56	17.8	34	13.9
Pearl Dace	29	8.2	3	0.7	3	1.0	30	12.3
River Chub	0	0.0	0	0.0	0	0.0	8	3.3
Rosyface Shiner	13	3.7	0	0.0	59	18.7	3	1.2
Mimic Shiner	56	15.9	59	14.1	0	0.0	62	25.4
Bluntnose Minnow	1	0.3	0	0.0	0	0.0	1	0.4
Blacknose Dace	0	0.0	1	0.2	1	0.3	3	1.2
Longnose Dace	30	8.5	0	0.0	0	0.0	1	0.4
Creek Chub	0	0.0	0	0.0	1	0.3	0	0.0
Fallfish	4	1.1	27	6.5	1	0.3	1	0.4
Chain Pickerel	3	0.9	0	0.0	1	0.3	0	0.0
Banded Killifish	0	0.0	1	0.2	0	0.0	0	0.0
Yellow Bullhead	2	0.6	1	0.2	0	0.0	0	0.0
Margined Madtom	20	5.7	21	5.0	23	7.3	40	16.4
Greenside Darter	15	4.3	24	5.7	26	8.3	5	2.0
Fantail Darter	2	0.6	0	0.0	0	0.0	0	0.0
Tessellated Darter	26	7.4	66	15.8	91	28.9	20	8.2
Banded Darter	11	3.1	30	7.2	21	6.7	11	4.5
Shield Darter	18	5.1	60	14.4	12	3.8	13	5.3
Brown Trout	1	0.3	1	0.2	0	0.0	0	0.0

Appendix 3. CPUE (#/hour) of fish species captured in Buffalo Creek and Pine Creek during electrofishing surveys conducted in 2010, 2011, 2012, and 2014.

	Buffalo Creek								Pine Creek							
	Strawbridge Rd. bridge				Footbridge at Rt. 1003				Ansonia Bridge				Darling Run			
	2010	2011	2012	2014	2010	2011	2012	2014	2010	2011	2012	2014	2010	2011	2012	2014
American Eel	33	73	15	15	8	10	19	26	0	2	31	`	0	2	4	8
Banded Darter	9	26	34	3	13	9	12	7	44	39	63	5	29	27	19	7
Banded Killifish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blacknose Dace	1	2	0	0	0	0	0	0	10	2	0	1	11	12	0	0
Bluegill	0	0	0	1	7	2	2	1	3	0	0	0	2	0	0	0
Bluntnose Minnow	0	93	6	0	1	8	2	0	0	10	3	0	0	14	26	0
Brown Trout	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Central Stoneroller	4	10	0	1	0	0	0	0	4	1	12	2	2	0	8	0
Chain Pickerel	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Common Carp	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Common Shiner	0	6	0	0	1	0	0	0	0	4	10	0	0	3	0	0
Creek Chub	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Creek Chubsucker	0	0	0	0	2	0	0	0	0	0	0	4	0	0	0	0
Cutlips Minnow	1	10	8	4	11	16	6	4	2	18	27	14	15	33	31	18
Fallfish	8	9	21	1	6	9	12	6	19	59	16	0	5	23	21	0
Fantail Darter	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0
Green Sunfish	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Greenside Darter	18	7	31	4	8	8	10	6	12	15	24	2	33	22	24	8
Largemouth Bass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Longnose Dace	9	8	19	9	0	1	3	0	15	2	7	0	0	6	0	0
Margined Madtom	13	26	24	6	11	3	4	5	19	68	48	16	9	38	13	7
Mimic Shiner	0	25	181	16	0	9	94	14	0	0	49	25	0	3	69	0
Mottled Sculpin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern Hogsucker	14	24	5	1	0	22	6	2	5	4	4	1	3	7	12	1
Pearl Dace	0	0	0	8	0	0	0	1	0	0	0	12	0	0	0	1
Pumpkinseed	0	4	0	0	2	8	1	0	0	0	0	0	0	0	0	0

Redbreast Sunfish	0	1	3	3	0	0	7	1	0	0	1	0	0	0	2	4
River Chub	0	0	0	0	0	0	0	0	0	0	19	3	0	0	9	0
Rockbass	0	1	5	8	15	7	8	5	9	0	0	0	8	0	7	2
Rosyface Shiner	0	18	20	4	0	0	5	0	8	50	22	1	14	176	41	19
Rosyside Dace	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Shield Darter	6	10	13	5	23	27	18	14	17	13	18	5	22	23	11	4
Shiner sp.	283	464	2	0	49	2	1	0	23	2	1	0	6	9	4	0
Shorthead Redhorse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Smallmouth Bass	1	2	6	3	5	2	11	7	0	1	4	0	0	6	4	2
Spotfin Shiner	0	1	3	0	1	1	5	0	0	0	0	0	0	0	0	0
Tessellated Darter	36	36	35	7	74	30	14	16	30	32	31	8	44	58	80	29
White Sucker	29	8	16	1	108	8	21	12	3	0	17	2	2	1	15	2
Yellow Bullhead	0	0	0	1	2	2	1	0	0	0	0	0	0	0	0	0