# Restoration Monitoring Of American Eel (Anguilla rostrata) In Three Southcentral Pennsylvania Streams In The Susquehanna River Basin (2015-2020)

*Publication No. 326*

Aaron Henning
Fisheries Biologist

October 2021

Celebrating 50 years 1971 - 2021 SRBC SUSQUEHANNA RIVER BASIN COMMISSION NY ▪ PA ▪ MD ▪ USA

## HISTORY OF AMERICAN EEL IN THE BASIN

The American eel (*Anguilla rostrata*) is a native, diadromous fish species occurring along the Atlantic slope and Gulf Coast river basins of North America. American eels rely on a complex catadromous life cycle which includes a migration into freshwater systems from their spawning grounds in the Sargasso Sea of the central Atlantic Ocean. The juvenile eels (elvers) ascend into freshwater systems to grow and mature and then out-migrate back into the ocean to spawn and complete their life cycle.

American eels were historically an important food source for indigenous peoples and early European settlers of the Susquehanna River Basin (Basin). Eels also were integral members of the Basin's aquatic community as predators and host species for the native mussel, Eastern Elliptio.

The construction of major hydroelectric dams in the early 20$^{th}$ century along the Susquehanna prevented eel migration in and out of the Basin. The Pennsylvania Fish and Boat Commission (PFBC; previously the Pennsylvania Fish Commission) stocked over 17 million American eels across Commonwealth rivers between 1936 and 1980 (PFBC unpublished data). Once those stocking efforts stopped, the American eel population in the Basin dropped significantly (Cooper, 1983), and eventually the eel was extirpated from the Basin (Minkkinen and Park, 2008).

In 2005, the United States Fish and Wildlife Service (USFWS) initiated a trap-and-transport restoration effort, installing a rudimentary eel trap near the base of Conowingo Dam in Darlington, MD, and upgrading and operating the trap through 2016. In spring 2016, Exelon Corporation (Exelon) began operating a seasonal eel ramp on Octoraro Creek in Lancaster County, PA, as part of a relicensing settlement agreement for the Muddy Run Pumped Storage Facility (FERC P-2355). In 2017, Exelon assumed responsibility for operating both eel ramps and transporting captured eels above the dams.

Eel collection and stocking is overseen by the Eel Passage Advisory Group (EPAG), which was formed as part of the Muddy Run settlement agreement and has representatives from Exelon, PFBC, USFWS, Susquehanna River Basin Commission (SRBC), the Pennsylvania Department of Environmental Protection (PADEP), the Maryland Department of Natural Resources (MDNR), and the Maryland Power Plant Research Program (MPPRP). The Maryland Department of Environment (MDE) joined EPAG when the Conowingo Hydroelectric Project was relicensed (FERC P-405).

Overlapping with the USFWS and Exelon efforts, the Susquehanna River Anadromous Fish Restoration Cooperative (SRAFRC) published an eel-specific restoration plan as an addendum to the existing Migratory Fish Management and Restoration Plan for The Susquehanna River Basin to guide future American eel restoration efforts (SRAFRC, 2013). One of the objectives of this plan is to study the success of these restoration efforts.

In 2015, SRBC initiated a monitoring project to investigate ecological impacts to streams receiving targeted stockings of American eel elvers. SRBC focused on the annual collection of biological and water quality data to document baseline conditions and track potential changes. This report summarizes observations from 2015 through 2020.

## STUDY DESIGN

American eels collected at the Octoraro Creek and Conowingo Dam ramps were stocked at three southcentral Pennsylvania sites: North Branch Muddy Creek near Brogue in York County, Conewago Creek near Aberdeen in Lancaster County, and Beaver Creek outside of Hummelstown in Dauphin County (Figure 1). Upstream watershed areas for these sites ranged in size from 24 to 43 square miles, are located within the Piedmont ecoregion, and possessed similar land use profiles featuring a mix of agriculture, forest, and urban development.

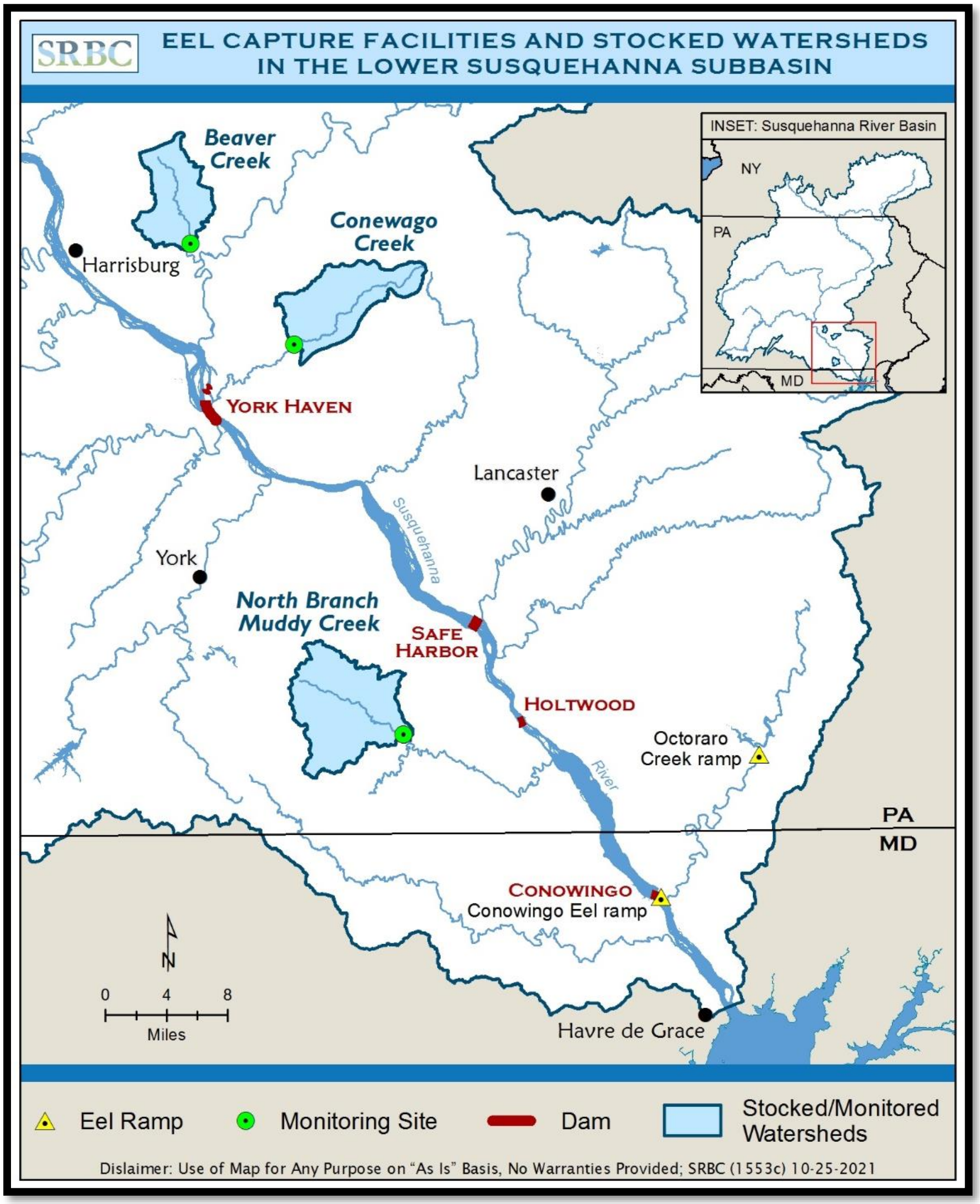


***Figure 1. Locations of American Eel Ramps and Experimentally Stocked Watersheds in the Lower Susquehanna River Basin***

Between May 2016 and June 2017, a total of 48,622 elvers were stocked at these three sites (Table 1). Specific stocking quantities were derived from USFWS guidance based on observations of American eel densities from free-flowing tributaries to the upper Chesapeake Bay. Stocking occurred at a single point on each stream which continued to serve as a monitoring location for the extent of this study. Elvers were stocked within one week of capture. Stocked elvers averaged 122mm in length and 2.1g in mass (Normandeau, 2017) and were approximately 1 to 4 years old, with a mean age of 1.65 years (Normandeau, 2020).

***Table 1. Cumulative American Eel Stocking By Year at SRBC Study Sites***

| **Waterbody** | **Stocking Goal** | **Stocked** | | |
|---|---|---|---|---|
| | | **2016** | **2017** | **Total** |
| North Branch Muddy Creek | 22,000 | 22,004 | 0 | 22,004 |
| Conewago Creek | 16,850 | 1,563 | 15,317 | 16,880 |
| Beaver Creek | 9,400 | 0 | 9,738 | 9,738 |
| **TOTAL** | **48,250** | **23,567** | **25,055** | **48,622** |

## MONITORING

Sampling occurred annually at each monitoring site and included collection of macroinvertebrates, crayfish, fish, and water samples, as well as assessments of stream characteristics. Macroinvertebrates were collected in fall using PADEP's riffle/run freestone macroinvertebrate collection protocol consisting of six 30-second kicks and a D-frame net (PADEP, 2013). The resulting composite sample was preserved in ethanol and was subsampled in the lab to a 200-organism subsample. Individual organisms were identified to genus when possible, and a small-stream macroinvertebrate Index of Biotic Integrity (IBI) score was calculated (PADEP, 2013).

Separate crayfish samples were collected in summer using a 1-$m^2$ quadrat sampler to obtain quantitative density estimates (Larson et al., 2008). Ten 1-meter quadrats were excavated at each monitoring site, and all captured crayfish were aggregated to create the sample for the site. Crayfish were then identified to species and weighed to obtain a biomass value for each species at each site. Time spent excavating was recorded and used to generate a catch per unit of effort (CPUE) rate.

Fish community data were collected in the summer via electrofishing following SRBC's single-unit wadeable electrofishing protocol using a MLES X-stream backpack unit (Shank et al., 2016). Three consecutive passes were made over a reach equivalent to ten times the average wetted stream width and covered left bank, right bank, and mid-channel habitats, respectively. All captured fish were identified to species and weighed in aggregate to attain a species level biomass value. All captured American eels were weighed and measured individually except during the initial year of stocking when a batch weight of the elvers caught was obtained. Beginning in 2019, all American eels over 200mm were implanted with an 8-mm full duplex Passive Integrated Transponder (PIT) tag. During each subsequent sampling event, individual eels were examined for the presence of a PIT tag by using a handheld PIT tag reader.

Water quality samples were collected quarterly at each monitoring location and consisted of six depth-integrated samples collected across the stream channel and composited into a churn splitter. Samples were lab analyzed for aluminum, iron, manganese, phosphorus, nitrate, total organic carbon, sulfate, sodium, and chloride. No storm-impacted samples were collected during water sampling.

Physical habitat was assessed visually at each site using the U.S. Environmental Protection Agency's (USEPA's) rapid bioassessment protocol for riffle/run wadeable streams (Barbour et al., 1999). Eleven possible habitat variables were evaluated on a scale of 1-20 with a maximum possible score of 220. Physical habitat was assessed in July or August. Representative site photographs were taken at least annually at each monitoring site to document changes in conditions.

## RESULTS

### Fish

American eels were shown to successfully establish themselves into the fish community at two of the three streams that were stocked—North Branch Muddy and Conewago Creeks. No eels have been documented at Beaver Creek since the initial post-stocking survey conducted in 2017.

Shannon Diversity Index (SDI) values and associated equitability index (EQI) values were calculated for each years' fish sample (Table 2). The SDI measures community diversity by looking at species abundance and evenness within a sampled community. The EQI measures the evenness of species distribution within the community (0 to 1 scale) based on the number of species recorded. SDI and EQI values remained above baseline values for Conewago and North Branch Muddy Creeks, where eel restoration was successful. SDI and EQI values in Beaver Creek were lower than in North Branch Muddy and Conewago Creeks. Hmax values, representing the theoretical maximum possible SDI of the community, were similar across all three sites.

***Table 2. Fish Assemblage Shannon Diversity Index Values (SDI) and Equitability Index Values (EQI) from Streams Receiving American Eel Stockings (Year of stocking is denoted in gray. Hmax represents the theoretical maximum possible SDI value.)***

| | North Branch Muddy | | Conewago | | Beaver | |
|---|---|---|---|---|---|---|
| **Year** | **SDI** | **EQI** | **SDI** | **EQI** | **SDI** | **EQI** |
| 2015 | 2.44 | 0.74 | 2.77 | 0.82 | 2.26 | 0.69 |
| 2016 | 2.42 | 0.73 | 2.84 | 0.85 | 1.77 | 0.54 |
| 2017 | 2.6 | 0.79 | 2.77 | 0.82 | 1.96 | 0.60 |
| 2018 | 2.59 | 0.79 | 2.84 | 0.85 | 1.89 | 0.57 |
| 2019 | 2.66 | 0.81 | 2.97 | 0.88 | 2.35 | 0.71 |
| 2020 | 2.56 | 0.78 | 2.85 | 0.85 | 2.19 | 0.67 |
| **Hmax** | 3.30 | | 3.36 | | 3.29 | |

The CPUE of American eels in Conewago and North Branch Muddy Creeks decreased with subsequent sampling events, while total American eel biomass increased (Tables 3 and 4). By 2020, American eels in the two streams were an average of 445mm in length and 200g in weight. Eels also contributed an average of 35 percent of the fish community biomass in these streams as well as 1.5 percent of the fish population abundance.

***Table 3. Annual Summary of American Eel Catch Per Unit of Effort, Individuals and Biomass and Mean Length/Weights from Stocked Streams***

| 2016 | | | | | |
|---|---|---|---|---|---|
| | **n** | **avg. length** | **avg. mass** | **CPUE (n/min)** | **Eel biomass (g/min)** |
| NB Muddy | 87 | 130 | NA | 1.7 | 9.3 |
| Conewago | NA | NA | NA | NA | NA |
| Beaver | NA | NA | NA | NA | NA |
| **2017** | | | | | |
| | **n** | **avg. length** | **avg. mass** | **CPUE (n/min)** | **Eel biomass (g/min)** |
| NB Muddy | 13 | 205.1 | 19.3 | 0.17 | 3.31 |
| Conewago | 37 | 156.8 | 6.1 | 0.88 | 4.8 |
| Beaver | 3 | 140 | 5 | 0.03 | 0.06 |
| **2018** | | | | | |
| | **n** | **avg. length** | **avg. mass** | **CPUE (n/min)** | **Eel biomass (g/min)** |
| NB Muddy | 14 | 349 | 85.2 | 0.21 | 17.54 |
| Conewago | 8 | 297.9 | 52 | 0.11 | 5.64 |
| Beaver | 0 | NA | NA | 0 | 0 |
| **2019** | | | | | |
| | **n** | **avg. length** | **avg. mass** | **CPUE (n/min)** | **Eel biomass (g/min)** |
| NB Muddy | 10 | 384 | 120.9 | 0.11 | 13.59 |
| Conewago | 6 | 362.3 | 72.5 | 0.07 | 4.98 |
| Beaver | 0 | NA | NA | 0 | 0 |
| **2020** | | | | | |
| | **n** | **avg. length** | **avg. mass** | **CPUE (n/min)** | **Eel biomass (g/min)** |
| NB Muddy | 12 | 465.8 | 244 | 0.17 | 42.12 |
| Conewago | 11 | 424.9 | 156.2 | 0.18 | 27.4 |
| Beaver | 0 | NA | NA | 0 | 0 |

***Table 4. Proportional Contribution of American Eel to Overall Fish Community Structure and Biomass at Successful Reintroduction Sites***

| | Conewago | | North Branch Muddy | |
|---|---|---|---|---|
| **Year** | **Abundance %** | **Biomass %** | **Abundance %** | **Biomass %** |
| 2015 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2016 | 0.0 | 0.0 | 13.8 | 8.3 |
| 2017 | 4.4 | 2.8 | 1.4 | 2.8 |
| 2018 | 2.3 | 6.6 | 4.3 | 22.9 |
| 2019 | <1.0 | 4.2 | 1.0 | 13.5 |
| 2020 | 1.8 | 20.2 | 1.3 | 40.0 |

Figure 2 displays the length and weight relationship for all American eels collected at the North Branch Muddy and Conewago Creek sites in the four years since reintroduction efforts began.

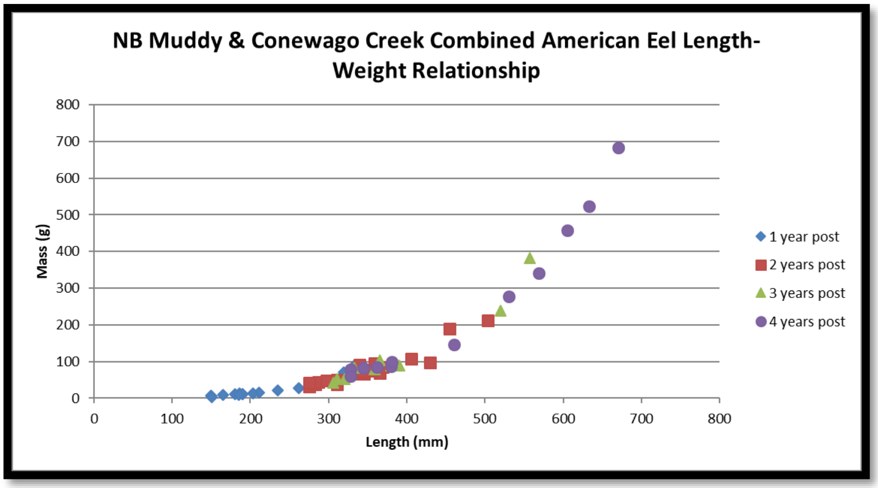


***Figure 2. Combined Length-Weight Relationship of American Eel Successfully Reintroduced to Two Streams***

## Crayfish

After eels were successfully reintroduced at the Conewago and North Branch Muddy sites, both crayfish CPUE and crayfish biomass decreased (Figures 3 and 4). Crayfish species at these two sites consisted of native Allegheny crayfish *(Faxonius obscurus)* and native Appalachian brook crayfish *(Cambarus bartonii)*. No non-native rusty crayfish (*Orconectes rusticus*) have ever been observed at the Conewago or North Branch Muddy Creek sites.

At Beaver Creek, where eel reintroduction was not successful, both crayfish CPUE and crayfish biomass have increased. These increases were accompanied by the continued invasion of rusty crayfish. Prior to introduction efforts, both Allegheny and rusty crayfish were observed, but by 2020, only rusty crayfish were observed at the site.

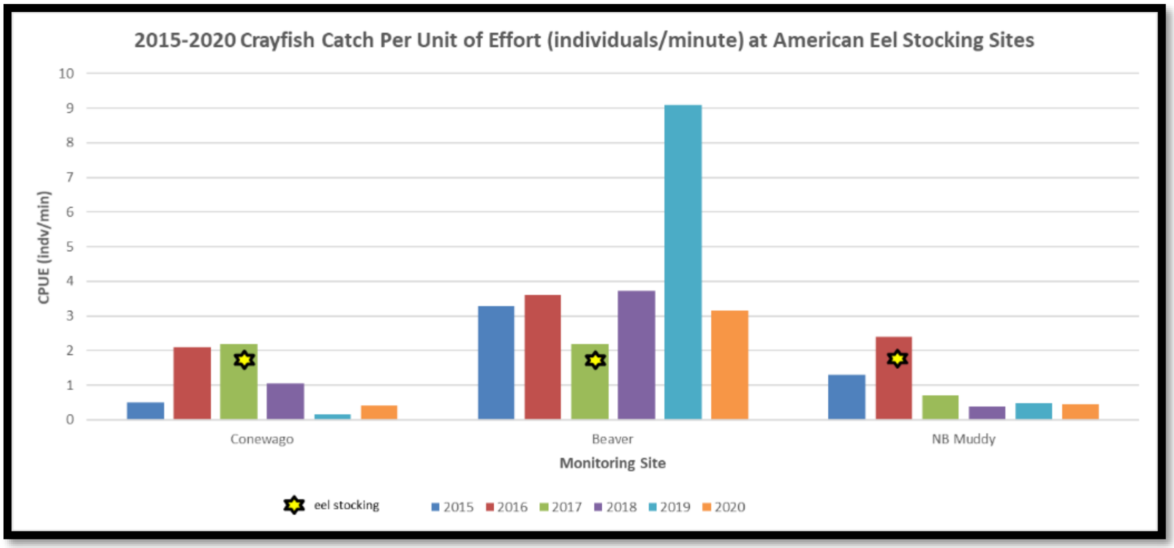


*Figure 3. Crayfish Catch Per Unit of Effort (n/min) at Streams Receiving American Eel Stockings (2015-2020)*

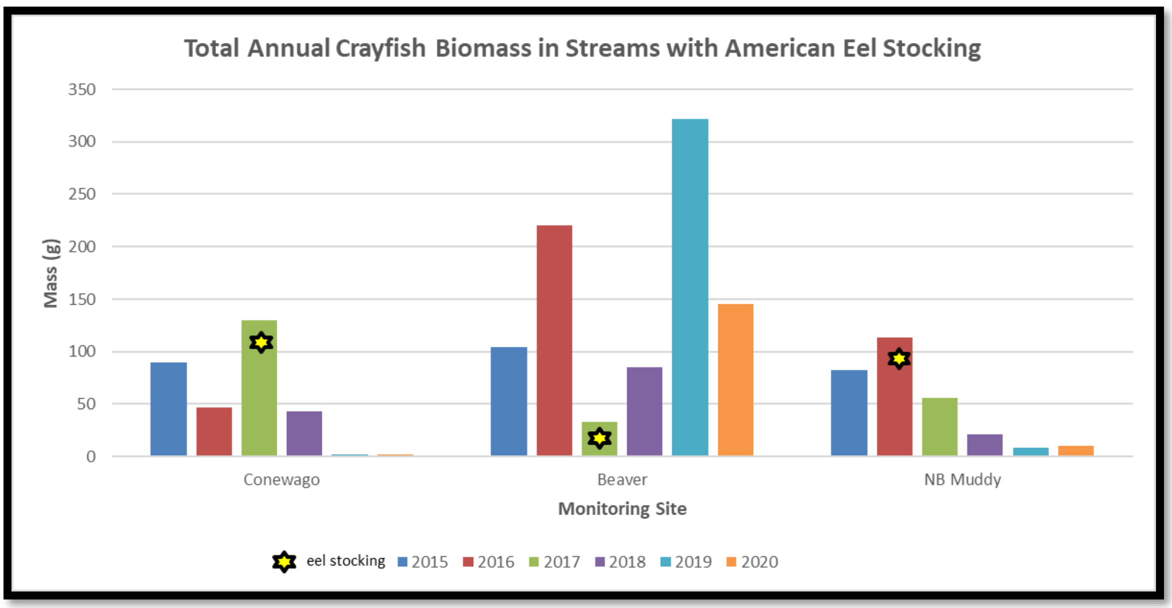


*Figure 4. Aggregated Crayfish Biomass at Streams Receiving American Eel Stockings (2015-2020)*

*Table 5. Crayfish Capture Rates, Densities, and Biomass from Streams Receiving American Eel Stockings, 2015-2020*

| | Group | Site | Total Individuals | Total Biomass (g) | Search Time (s) | CPUE (indv/min) | Density (indv/m$^2$) | Biomass (g/min) | Biomass (g/m$^2$) | % Rusty crayfish |
|---|---|---|---|---|---|---|---|---|---|---|
| 2015 | SCPA | Conewago | 9 | 89.2 | 1050 | 0.5 | 0.9 | 5.10 | 8.92 | 0.00 |
| | SCPA | Beaver | 40 | 104.4 | 738 | 3.3 | 4 | 8.49 | 10.44 | 98.00 |
| | SCPA | NB Muddy | 20 | 82.1 | 892 | 1.3 | 2 | 5.52 | 8.21 | 0.00 |
| 2016 | SCPA | Conewago | 34 | 46.8 | 950 | 2.1 | 3.4 | 2.96 | 4.68 | 0.00 |
| | SCPA | Beaver | 51 | 220.5 | 840 | 3.6 | 5.1 | 15.75 | 22.05 | 84.00 |
| | SCPA | NB Muddy | 40 | 113.5 | 1020 | 2.4 | 4 | 6.68 | 11.35 | 0.00 |
| 2017 | SCPA | Conewago | 25 | 129.5 | 672 | 2.2 | 2.5 | 11.56 | 12.95 | 0.00 |
| | SCPA | Beaver | 31 | 33.07 | 844 | 2.2 | 3.1 | 2.35 | 3.31 | 100.00 |
| | SCPA | NB Muddy | 8 | 55.6 | 717 | 0.7 | 0.8 | 4.65 | 5.56 | 0.00 |
| 2018 | SCPA | Conewago | 21 | 43.17 | 1206 | 1.0 | 2.1 | 2.15 | 4.32 | 0.00 |
| | SCPA | Beaver | 44 | 85.14 | 710 | 3.7 | 4.4 | 7.19 | 8.51 | 100.00 |
| | SCPA | NB Muddy | 8 | 20.72 | 1273 | 0.4 | 0.8 | 0.98 | 2.07 | 0.00 |
| 2019 | SCPA | Conewago | 2 | 1.53 | 768 | 0.2 | 0.2 | 0.12 | 0.15 | 0.00 |
| | SCPA | Beaver | 118 | 322.05 | 778 | 9.1 | 11.8 | 24.84 | 32.21 | 100.00 |
| | SCPA | NB Muddy | 7 | 8.71 | 884 | 0.5 | 0.7 | 0.59 | 0.87 | 0.00 |
| 2020 | SCPA | Conewago | 6 | 2.35 | 892 | 0.4 | 0.6 | 0.16 | 0.24 | 0.00 |
| | SCPA | Beaver | 33 | 145.6 | 628 | 3.2 | 3.3 | 13.91 | 14.56 | 100.00 |
| | SCPA | NB Muddy | 6 | 10.02 | 803 | 0.4 | 0.6 | 0.75 | 1.00 | 0.00 |

## Macroinvertebrates

Macroinvertebrates are very useful indicators of overall stream health, which can be measured by Index of Biotic Integrity (IBI) scores. All three monitoring sites had increases in IBI scores from 2015 to 2020 (Figure 5).

Conewago Creek, where reintroduction was successful, experienced the biggest increase in IBI scores from 2015 through 2020. Reintroduction was also successful at North Branch Muddy Creek, but IBI scores fluctuated over the study period, and scores at the beginning and end of the study period were similar. While eel reintroduction was not successful in Beaver Creek, IBI scores at this site tracked with the fluctuation pattern observed at North Branch Muddy Creek.

IBI metrics provide useful information to document stream health across geographic and temporal scales. Short-term effects from American eel reintroduction, however, may be undetectable using this approach, and IBI scores are also greatly affected by local influences.

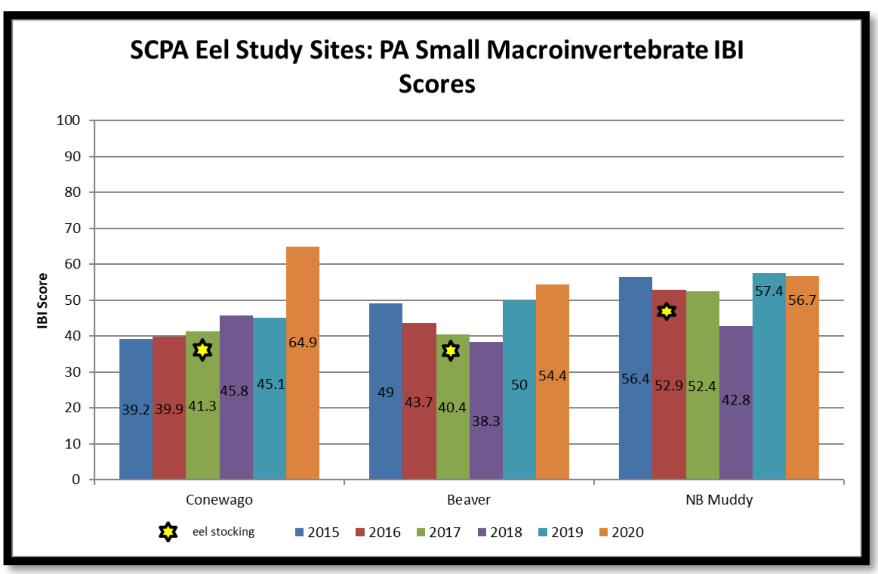


*Figure 5. Macroinvertebrate-based Index of Biological Integrity (PA Freestone) Scores for Streams Receiving American Eel Stockings (2015-2020)*

## Habitat

Habitat scores were consistent through time at each monitoring site (Figure 6), with no significant changes in surrounding land use or disturbances to instream or riparian habitat being observed. Generally, bank conditions and riparian zone widths were the lowest scoring individual parameters at all monitoring sites. Instream habitat at North Branch Muddy Creek and Conewago Creek is more varied and complex, featuring undercut banks and mixed velocity/depth regimes, yielding suboptimal habitat conditions and scores. In contrast, overall habitat at Beaver Creek was deemed marginal while Conewago and North Branch Muddy Creeks had suboptimal habitat conditions.

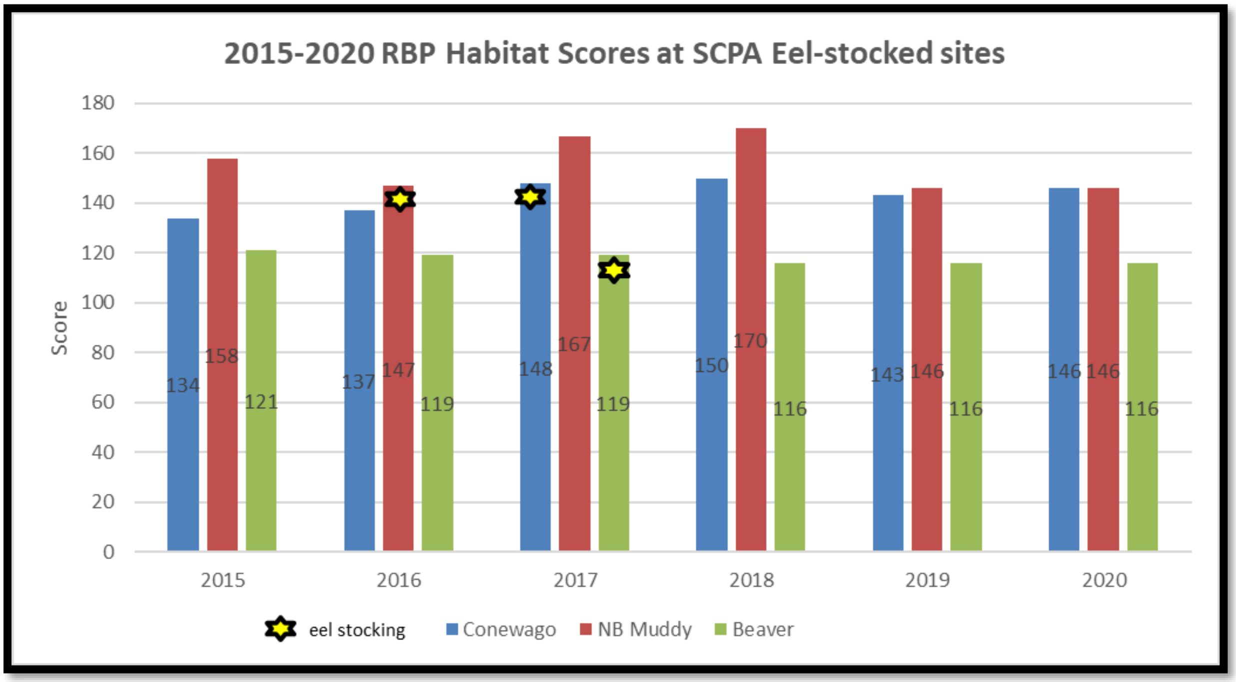


*Figure 6. Total RBP Habitat Scores at American Eel Stocked Monitoring Locations (2015-2020)*

## Water Quality

Water quality index values were calculated using SRBC's Development of a Water Quality Index (WQI) for the Susquehanna River Basin (Berry et al., 2020). The Susquehanna WQI converts raw concentrations of nine commonly monitored parameters into a unitless number between 0 and 100 (the greater the number, the better the water quality). The nine parameters are grouped into three categories to generalize the presence of different disturbances: mine drainage/metals (aluminum, iron, and manganese); nutrient enrichment (nitrate, total phosphorus, and total organic carbon); and development (chloride, sodium, and sulfate).

For each water sample, the value of each parameter was scored based on a percentile ranking of that concentration in a reference dataset of values within the Basin. Each parameter score within a category was then averaged into a categorical score. The three categorical scores were then averaged to produce an aggregate WQI score. Since the WQI is correlated with biological assemblage and land use data, WQI scores can be useful water quality assessment tools for use within the Basin. SRBC has assigned categorical values to correspond to WQI numeric values as follows: Excellent (>85), Good (62-85), Fair (43-62), Poor (31-43), and Very Poor (<31). Aggregate WQI scores were calculated for samples collected in 2020, while only development and nutrient enrichment categorical scores could be calculated for samples collected from 2015 through 2019.

WQI scores varied by season within 2020, with the lowest scores occurring at Conewago and the highest scores generally occurring at North Branch Muddy Creek (Figure 7). Conewago Creek rated the lowest (Poor to Very Poor) and had the lowest WQI scores of the three sites. Conewago Creek suffers from developmental pressures and nutrient enrichment (Figures 8 and 9). Beaver Creek ratings ranged from Fair to Poor and also appeared to be affected more by development than by nutrient enrichment. North Branch Muddy Creek rated the highest of the three sites (Fair) and was less affected by development and nutrient enrichment than the other two sites. With overall categorical scores persisting in the Fair to Poor ranges, human influence is apparent in all three watersheds and reflected differently in WQI categorical scores.

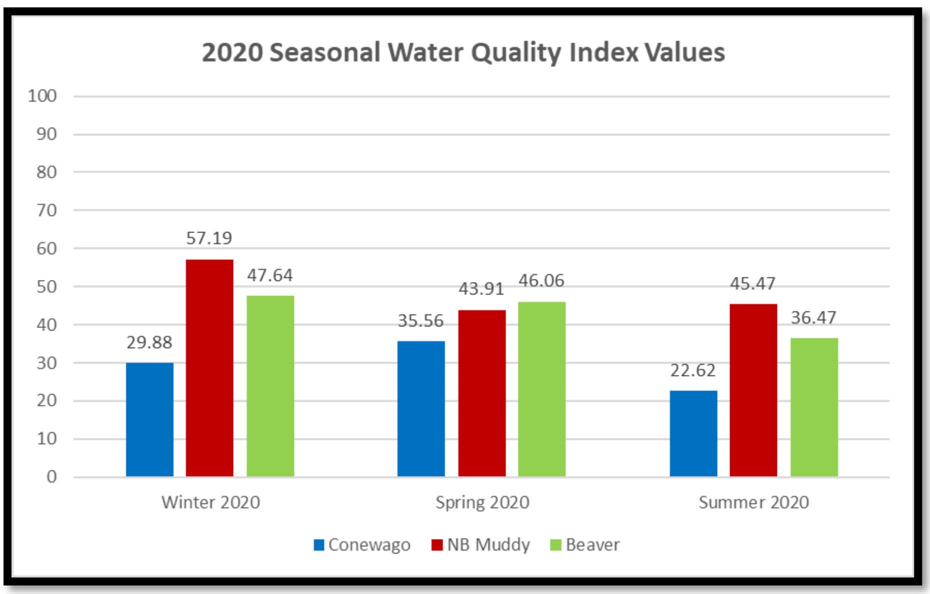


***Figure 7. Susquehanna WQI Values By Season at American Eel Stocked Monitoring Locations***

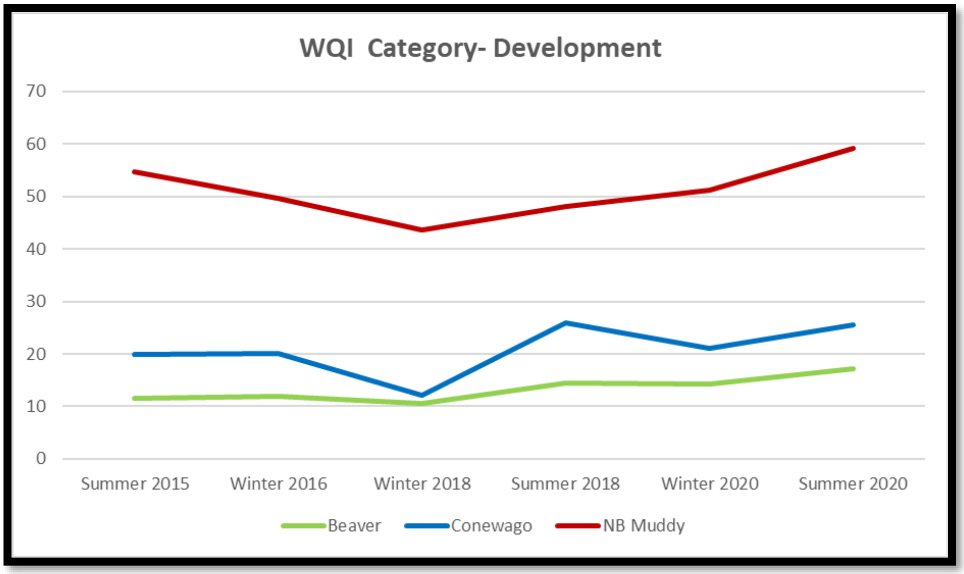


***Figure 8. Development Category Scores Through Time at Eel-stocked Monitoring Sites***

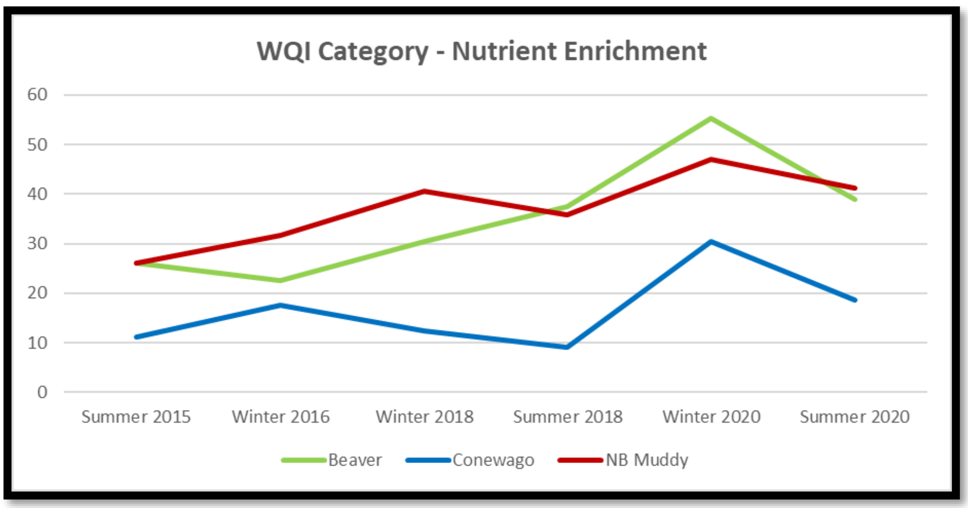


***Figure 9. Nutrient Enrichment Category Scores Through Time at Eel-stocked Monitoring Sites***

## DISCUSSION

This study examined site-level changes in biological communities, habitat conditions, and water quality associated with the reintroduction of American eels to three watersheds. American eels successfully established themselves in two of the three study streams (North Branch Muddy and Conewago creeks). Additionally, American eels have since been collected at multiple locations upstream and downstream of the stocking sites on these two streams during unrelated electrofishing surveys (PFBC personal communication; Kyler and Hill, 2018).

No American eels have been collected in Beaver Creek since the initial stocking event. Subsequent annual surveys at the stocking site and two locations upstream and downstream of the stocking site, have also failed to document the presence of any eels (Normandeau Associates, 2018).

American eels have been shown to occupy a variety of degraded habitats and can endure poor water quality (Greene et al., 2009). The apparent inability of Beaver Creek to support American eels introduces a significant unknown factor into the overall restoration effort since physical habitat was marginal and water quality fair or poor at Beaver Creek compared to the other sites where eels successfully colonized. While ascertaining the cause for the failure to establish in Beaver Creek may be impossible, the scenario is noteworthy as future directed stockings may suffer similar outcomes.

This study generally followed the methodology of a recently concluded USFWS American eel stocking study which occurred in the Pine and Buffalo Creek Watersheds within the Susquehanna Basin (Minkkinen, 2019). While the watersheds stocked by USFWS were larger than the watersheds involved in this SRBC study, both USFWS watersheds noticed successful reestablishment of American eels in varied habitats and water quality conditions. USFWS noted increased freshwater mussel recruitment in both watersheds following American eel reintroduction but identified poor habitat and water quality as mussel-limiting factors in the Buffalo Creek Watershed.

The reintegration of American eel into the fish assemblage yielded no apparent deleterious impacts to other extant species of interest. North Branch Muddy Creek supports a naturally reproducing wild brown trout fishery and receives supplemental stocking through the PFBC's Cooperative Nursey Program. Wild brown trout have been documented at this site every year except 2016, ranking in the top five species for contribution to overall biomass (6.9 to 14.4 percent) when documented.

A previous study in Maryland indicated that crayfish density is not affected by the presence of eels (Stranko et al., 2014). The results of this study show overall crayfish abundance and biomass declines in the presence of American eels. No such decline was apparent in Beaver Creek where reintroduction failed and non-native rusty crayfish (*Faxonis rusticus)* are dominant. No rusty crayfish were found at the sites with successful reintroduction.

The omnivorous rusty crayfish are larger and can outcompete native species for habitat and food resources (Bobeldyk and Lamberti, 2008). The mainstem Susquehanna River and many direct tributaries now support expanding rusty crayfish populations. Furthermore, a separate sampling effort at a location approximately 10 miles downstream of the monitoring site on Conewago Creek yielded rusty crayfish, indicating an ongoing invasion of the watershed.

A diet study of American eels from New Jersey revealed an increased proportion of crustaceans in the stomach contents of larger eels (Ogden, 1970). Similarly, large American eels (>500mm) collected during boat-electrofishing surveys of the Susquehanna River were observed actively excreting crayfish chela (Henning unpublished data, 2019). Another study focusing on feeding selectivity of eels from the Upper Delaware River suggested opportunistic predation on many varied macroinvertebrates (Denoncourt and Stauffer, 1993). The established propensity for eels to opportunistically feed on abundant prey sources suggests a potential for American eels to act as a mechanism for biological control or mitigation of the rusty crayfish that currently exist within the Susquehanna. Recently documented densities of up 30 rusty crayfish individuals/$m^2$ in the mainstem Susquehanna River demonstrate a considerable crayfish forage base for eels (Mangan et al., 2014).

Continued research on American eel restoration in smaller settings can help understand additional nuances to reintroduction success. Additional research is also needed to document contemporary dietary preferences of eels of various size classes as well as specific aspects of eel ecology and life history within the Susquehanna River. In addition, researchers need to understand more about how the density of American eels can affect sex determination of individuals. Purposeful manipulation of stocking densities in the Susquehanna River, combined with adequate monitoring, could answer these questions.

## CONCLUSION

The results of this study reinforce the need for robust and routine ecological monitoring of freshwater systems. The Susquehanna River and many tributaries exist in highly altered states relative to historic conditions as well as to current conditions in neighboring free-flowing drainages. The American eel restoration effort underway in the Susquehanna Basin marks a significant step towards re-establishing a keystone species within its native ecosystem. The results seen in this small-scale monitoring project will hopefully inform and guide subsequent, related efforts in the future. The need for this targeted multi-dimensional ecological monitoring is apparent in the preliminary results from this study as well as the related USFWS experimental stocking study. While American eels are generally rather tolerant fish, their ability to successfully refill their previously vacated ecological niches should be considered in future stocking decisions. As long-term restoration goals are focused on the joint recovery of American eels and freshwater mussels in the Susquehanna River Basin, suitable locations which can best support the greatest diversity of freshwater fauna should be prioritized.

## REFERENCES

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water; Washington, D.C.

Berry, J., L. Steffy, and M. Shank. 2020. Development of a Water Quality Index (WQI) For the Susquehanna River Basin. Susquehanna River Basin Commission Publication No. 322. Harrisburg, Pennsylvania.

Bobeldyk, A.M. and G.A. Lamberti. 2008. A decade after invasion: evaluating the continuing effects of rusty crayfish on a Michigan river. Journal of Great Lakes Research 34: 265-275.

Cooper, Edwin L. 1983. The Fishes of Pennsylvania and the Northeastern United States. The Pennsylvania State University Press, University Park and London.

Denoncourt, Charles E. and Jay Stauffer, Jr. 1993. Feeding selectivity of the American eel *Anguilla rostrata* (LeSuer) in the Upper Delaware River. American Midland Naturalist. Vol. 129, No. 2, pp. 301-308.

Distefano, R.J. et al. 2003. A sampling Method to Assess Lotic Crayfish Communities. Journal of Crustacean Biology 23 (3): 678-690.

Greene, K.E., J.L. Zimmerman, R.W. Laney, and J.C. Thomas-Blate. 2009. Atlantic coast diadromous fish habitat: A review of utilization, threats, recommendations for conservation, and research needs. Atlantic States Marine Fisheries Commission Habitat Management Series No. 9, Washington, D.C.

Kyler, Kristen and Ryan Hill. 2018. The Conewago Creek Revisited Fish Survey Report. Penn State Agriculture and Environment Center for the Conewago Creek Initiative.

Larson, E.R. et al. 2008. Efficiency of a Quadrat Sampling Technique for Estimating Riffle-Dwelling Crayfish Density. North American Journal of Fisheries Management 28: 1036-1043.

Mangan, Brian P., M. Bilger., S. Reese. & R. Michener. 2014. Rusty Crayfish and Smallmouth Bass in the Susquehanna River: Who’s eating Whom? Final Report to Pennsylvania Sea Grant.

Minkkinen, S. and I. Park. 2008. American Eel sampling at Conowingo Dam 2008. United States Fish and Wildlife Service. Maryland Fisheries Resource Office.

Minkkinen, Steven P. 2019. Experimental Stocking of American eels in the Susquehanna River Watershed 2019 Annual Report / Final Report. Maryland Fish and Wildlife Conservation Office.

Normandeau Associates, Inc. 2020. Muddy Run Pumped Storage Project Conowingo Eel Collection Facility. FERC Project No. 2355. Prepared for Exelon.

Normandeau Associates, Inc. 2018. Muddy Run Pumped Storage Project Periodic Evaluation of Upstream Stream Segments, 2018. FERC Project No. 2355. Prepared for Exelon.

Normandeau Associates, Inc. 2017. Muddy Run Pumped Storage Facility Conowingo Eel Collection Facility. FERC Project No. 2355.

Ogden, John C. 1970. Relative Abundance, Food Habits, and Age of the American Eel *Anguilla rostrata (LeSueur)* in Certain New Jersey Streams. Transactions of the American Fisheries Society, 99: 54-59.

Pennsylvania Department of Environmental Protection (PADEP). 2013. A Benthic Macroinvertebrate Index of Biological Integrity for Wadeable Freestone Riffle-Run Streams in Pennsylvania. Division of Water Quality Standards, PADEP.

Shank, M., A. Henning, and A. Leakey. 2016. Examination of a Single-Unit, Multiple-Pass Electrofishing Protocol to Reliably Estimate Fish Assemblage Composition in Wade Streams of the Mid-Atlantic Region of the USA, North American Journal of Fisheries Management, 36:3, 497-505.

Stranko, Scott A., Matthew J. Ashton, Robert H. Hildebrand, Sara Weglein, David C. Kazyak and Jay V. Killian. 2014. Fish and Benthic Macroinvertebrate Densities in Small Streams with and without American Eels, Transactions of the American Fisheries Society, 143:3, 700-708.

Susquehanna River Anadromous Fish Restoration Cooperative. 2013. American Eel Restoration Plan for the Susquehanna River Basin – Addendum to the Susquehanna River Anadromous Fish Restoration Cooperative (SRAFRC) 2010 Migratory Fish Management and Restoration Plan for the Susquehanna River Basin.