An Ecological Study of Gunston Cove

2018

FINAL REPORT

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by

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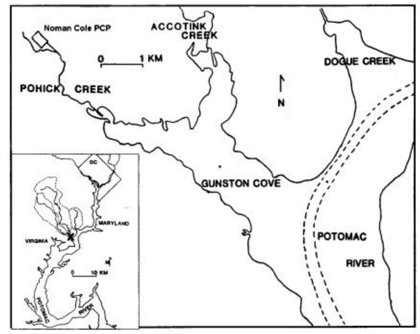
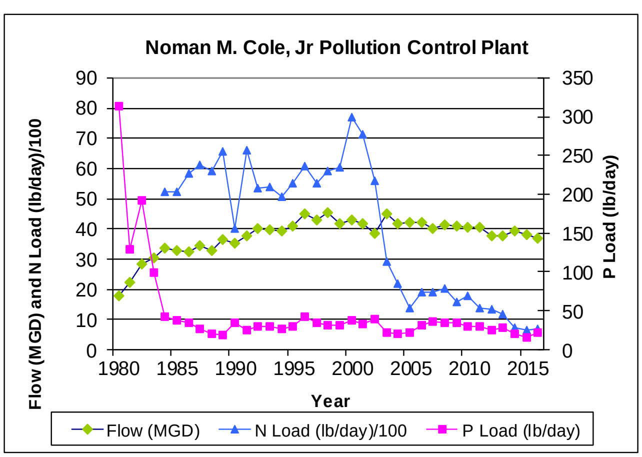
Executive Summary



Gunston Cove is an embayment of the tidal freshwater Potomac River located in Fairfax County, Virginia about 12 miles (20 km) downstream of the I-95/I-495 Woodrow Wilson Bridge. The Cove receives treated wastewater from the Noman M. Cole, Jr. Pollution Control Plant and inflow from Pohick and Accotink Creeks which drain much of central and southern Fairfax County. The Cove is bordered on the north by Fort Belvoir and on the south by the Mason Neck. Due to its tidal nature and shallowness, the Cove does not seasonally stratify vertically, and its water mixes gradually with the adjacent tidal Potomac River mainstem. Thermal stratification can make nutrient management more difficult, since it can lead to seasonal oxygen-diminished bottom waters that may result in fish mortality. Since 1984 George Mason University personnel, with funding and assistance from the Wastewater Management Program of Fairfax County, have been monitoring water quality and biological communities in the Gunston Cove area including stations in the Cove itself and the adjacent River mainstem. This document presents study findings from 2017 in the context of the entire data record.

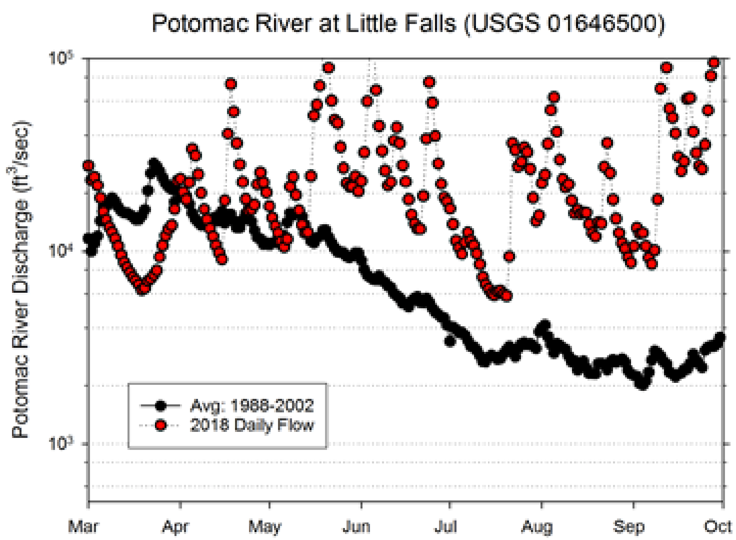
The Chesapeake Bay, of which the tidal Potomac River is a major subestuary, is the largest and most productive coastal system in the United States. The use of the bay as a fisheries and recreational resource has been threatened by overenrichment with nutrients which can cause nuisance algal blooms, hypoxia in stratified areas, and a decline of fisheries. As a major discharger of treated wastewater into the tidal Potomac River, particularly Gunston Cove, Fairfax County has been proactive in decreasing nutrient loading since the late 1970's. Due to the strong management efforts of the County and the robust monitoring program, Gunston Cove has proven an extremely valuable case study in eutrophication recovery for the bay region and even internationally. The onset of larger areas of SAV coverage in Gunston Cove will have further effects on the biological resources and water quality of this part of the tidal Potomac River.



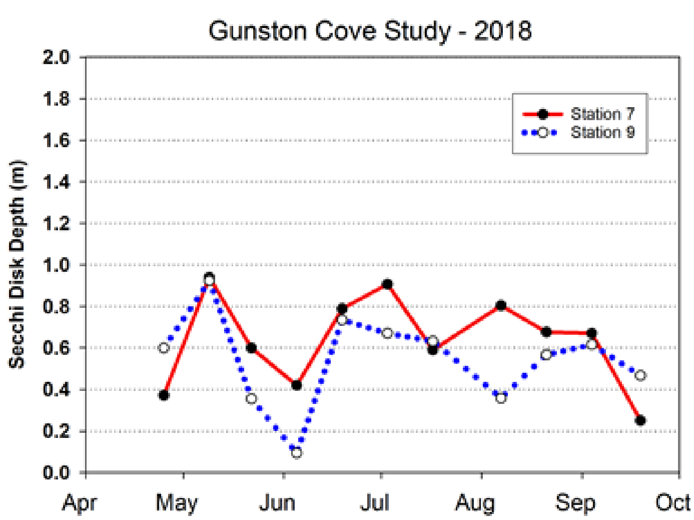
As shown in the figure to the left, phosphorus loadings were dramatically reduced in the early 1980's. In the last several years, nitrogen, and solids loadings as well as effluent chlorine concentrations have also been greatly reduced or eliminated. These reductions have been achieved even as flow through the plant has slowly increased.

The ongoing ecological study reported here provides documentation of major improvements in water quality and biological resources which can be attributed to those efforts. Water quality improvements have been substantial in spite of the increasing population and volume of wastewater produced. The 35 year record of data from Gunston Cove and the nearby Potomac River has revealed many important long-term trends that validate the effectiveness of County initiatives to improve treatment and will aid in the continued management and improvement of the watershed and point source inputs.

The year 2018 was a year of record rainfall in the Fairfax area. Precipitation was above normal for the entire study period and well above normal during May, July and September. The excessive rainfall and resulting runoff had a strong impact on multiple parameters, especially after especially high rainfall periods in mid May and late July. Both Potomac River flows (right) and Accotink Creek tributary flows were highly elevated.

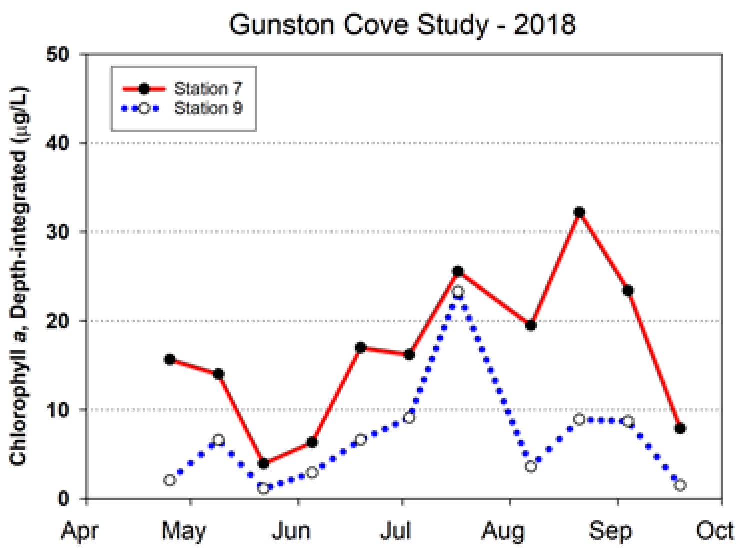


Mean water temperature was similar at the two stations with a pronounced dip in late May and a peak of about 30° in early September. Specific conductance declined substantially at both stations in the wake of the late May flow events. Dissolved oxygen saturation and concentration (DO) were normally substantially higher in the cove than in the river apparently due to photosynthetic activity of phytoplankton alone, since SAV was very limited in 2018. Field pH patterns mirrored those in DO: higher values in the cove than the river. Secchi disk transparency (figure at left) and light attenuation coefficient were both strongly decreased in late May and early June and turbidity increased at that time. The response to the July flows was not as clearcut.

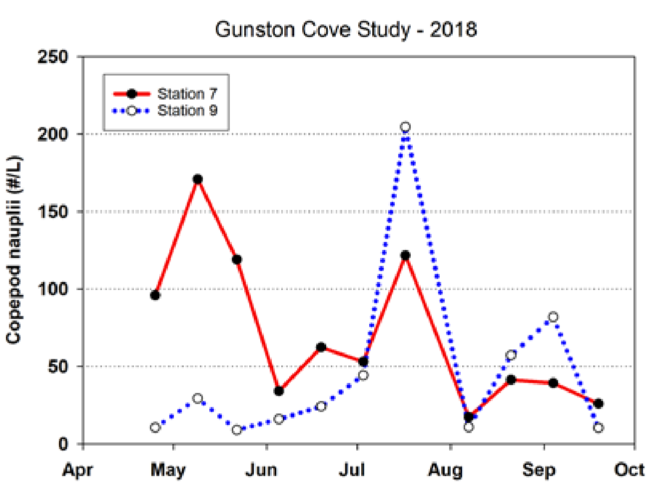


Ammonia nitrogen was consistently low in the study area during 2018, but all values were below the limits of detection making analysis of any temporal or spatial trends impossible. Nitrate values declined strongly in late May, probably due to the storm flushing. A second decline observed in July was likely due to phytoplankton uptake. Organic nitrogen in the cove showed a strong decline in response to the May high flows, but there was no response to the July flows. River organic nitrogen did not seem to be flow related. Total phosphorus was generally somewhat higher at the river station and showed little seasonal change or response to the flow events. N to P ratio did not show a consistent seasonal pattern, but was generally in the 12-30 range which is still indicative of P limitation of phytoplankton and SAV. TSS in the river responded strongly to the May and July flow events by doubling. In the cove a strong response was seen to the July, but not to the May high flows.

In the cove algal populations as measured by chlorophyll *a* were consistently higher in the cove than in the river and showed a clear response to flow events (figure at right). Promising values in the spring in the cove were dramatically decreased by the late May flow event. A steady increased followed through mid July. Values in the cove dropped back slightly in early August in response to high July flows and then again in September in response to renewed high flows. Total cell density values did not track chlorophyll levels very well. Cell density in the cove was dominated by cyanobacteria, with *Oscillatoria*, *Chroococcus*, and *Anabaena* being the dominants. Phytoplankton biovolume tracked chlorophyll a better exhibiting the seasonal pattern of values peaking in late July. Diatoms greatly dominated phytoplankton biovolume with *Melosira* and discoid centrics making the greatest contributions and being responsible for the July peak..

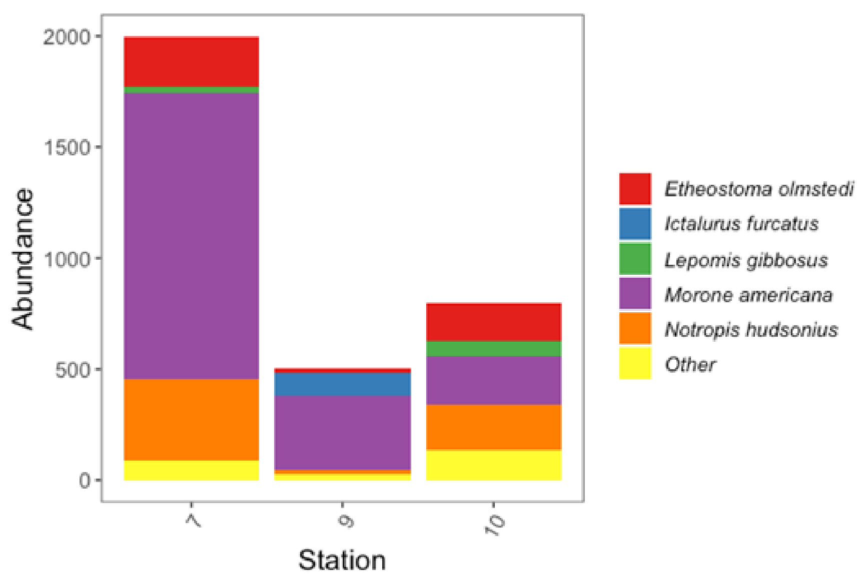


Rotifers continued to be the most numerous zooplankton in 2018. Rotifer densities were unusually high in early May in the cove and the river with *Keratella* dominant in the cove and *Ploesoma* in the river. These values were greatly diminished in late May and early June due to flushing from the high flows. Rotifer populations recovered during June and July attributable to *Brachionus*, *Filinia*, and *Keratella*. A decline then



ensured perhaps due to flushing. *Bosmina*, a small cladoceran, was strongly impacted by the May and July flow events. *Diaphanosoma* and *Daphnia*, larger cladocerans were strongly impacted by the May and July flow events. Copepod nauplii densities (figure above) exhibited a clear response to the late May and late July flow events suffering large losses. The calanoid copepod *Eurytemora* was very abundant in the cove in April and early May, but declined greatly in late May and June. Cyclopoid copepods had a strong maximum in the cove in early May and in the river in late August.

In 2018 ichthyoplankton was dominated by clupeids, most of which were Alewife, Gizzard Shad, and Blueback Herring, and to a lesser extent Hickory Shad, and American Shad. Although clupeids constituted more than 90% of the catch, 13 different species were identified in the ichthyoplankton samples. Of those, White Perch was found in relatively high densities. White Perch was mostly found in the Potomac mainstem, confirming its affinity for open water. Other taxa were found in very low densities similar to the previous year. The highest density of fish larvae occurred at the start of May, which was driven by a high density of Clupeid larvae in combination with relative density of other larvae. The non-clupeid larval density was highest in spring with a second peak in early July, which was Inland Silverside larvae.



Unlike previous years, submerged aquatic vegetation had very low cover, which has an effect on fish sampling. As a result, all trawl and seine stations could be sampled throughout the season, and the fyke nets were not very effective. In trawls (figure on the right), White Perch dominated with 55.6% of the catch, followed by Spottail Shiner and Tessellated Darter. White Perch was found in all months at all stations, with peak abundance in July. More than a hundred invasive Blue Catfishes were collected with the trawl in the river with two additional ones in the cove. While our cove trawl stations were unobstructed by SAV this year, we still found a large disparity between catches of Blue Catfish in the mainstem versus the cove, which supports the theory that Blue Catfish has an affinity for the mainstem, potentially leaving embayments like Gunston Cove to serve as a refuge for native catfishes. We collected thirty-seven native catfishes within Gunston Cove, of which 23 were brown bullhead, and 14 were white bullhead. In general, these species have been on the decline since the invasion of Blue Catfish.

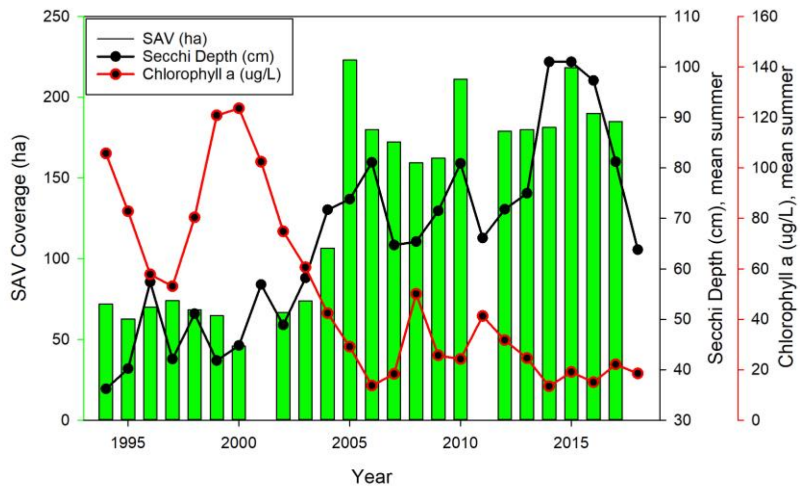
In seines, the most abundant species in 2018 was Banded Killifish (*Fundulus diaphanus*) which composed 42.6% of seine-collected fish. Banded Killifish was far more abundant in seines than in trawls, which emphasizes the preference of Banded Killifish for the shallow littoral zone (which is the area sampled with a seine, while trawls sample the open water). The abundance peak of Banded Killifish was in May and June. Other taxa with high abundances were Herring and Shad, which together came close to being as abundant as Banded Killifish. Numerous small Alosa juveniles started appearing in the samples in early June, after the spring spawning of river herring and American Shad. This is a good sign for this group of species that has been on the decline coastwide. Abundances remained high throughout the sampling season with a peak in September, which includes the non-anadromous clupeid Gizzard Shad. Other relatively abundant species collected with the seines were White Perch and Tessellated Darter.

Fyke nets were part of the sampling regime again in 2018. The total catch of the fyke nets is smaller than the other gears, and was much smaller than previous years since avoidance by fish is higher when the stationary nets are not hidden by SAV cover. However, it still represents an interesting contribution to the total catch because the composition of the catch in fyke nets is different than the trawls and seines. Sunfishes were the most dominant taxa, with Inland Silverside as the second most abundant species. Sunfishes that could be identified to the species level were represented in order of abundance by Pumpkinseed, Bluegill, and Green Sunfish. Overall catches were low with highest abundance in August.

As in most previous years, oligochaetes were the most common invertebrates collected in ponar samples in 2018. Amphipods were common at both stations. Chironomids were also common in the cove and bivalves in the river. Multivariate analysis showed a clear and consistent difference between cove benthic communities and those in the river.

The coverage of submersed aquatic vegetation (SAV) in 2018 was very limited in contrast to every year since 2004. The major problem seems to be the high turbidity and subsequent low light levels mainly due to inorganic sediments brought in or resuspended by the May flow events. Then this was followed by other flow events in July and September. The exotic plant *Hydrilla* did better than other taxa, but was present in a smaller area and at much lower densities than in previous years. Unfortunately, due to a combination of factors, including poor water clarity in September, VIMS was unable to provide the standard aerial survey which would have documented the full extent of the dieback.

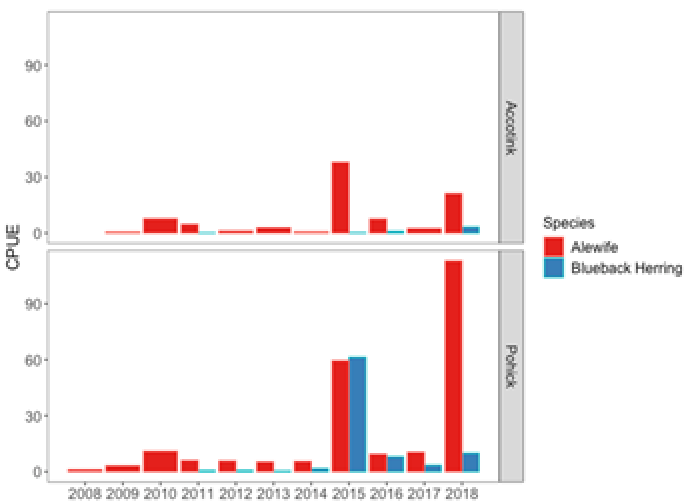
As noted previously, standaridized data on SAV coverage from VIMS was not available in 2018, but it was very clear that coverage was highly reduced from previous years. As shown in the figure to the right, phytoplankton chlorophyll remained at the low values characteristic of the last decade so it does not appear that phytoplankton shading was responsible for the depauperate state of the SAV community. Rather inorganic turbidity brought in or resuspended by the frequent storms in 2018 was the cause of the decline in SAV.



A second significant change in water quality documented by the study has been the removal of chlorine and ammonia from the Noman M. Cole, Jr. Pollution Control Plant effluent. A decline of over an order of magnitude in ammonia nitrogen has been observed in the Cove as compared to earlier years. The declines in ammonia and the elimination of chlorine from the effluent (to values well below those that may result is toxicity problems) have allowed fish to recolonize tidal Pohick Creek which now typically has more spawning activity than tidal Accotink Creek. Monitoring of creek fish allowed us to observe recovery of this habitat which is very important for spawning species such as shad. The decreased ammonia, suspended solids, and phosphorus loading from the plant have contributed to overall Chesapeake Bay cleanup. Unfortunately, we are unable to continue to track further declines in ammonia concentrations since all values are now below the detection limit reported by the County.

Another trend of significance which is indicative of the Cove recovery is changes in the relative abundance of fish species. While it is still the dominant species in trawls, White Perch has gradually been displaced in seines by Banded Killifish. This trend continued in 2017 with Banded Killifish being much more abundant in seines than White Perch. In general this is a positive development as the net result has been a more diverse fish community. Blue Catfish have entered the area recently and were quite abundant in 2018. Blue Catfish are regarded as rather voracious predators and may negatively affect the food web. Interestingly, Brown Bullhead which is a potential competitor of Blue Catfish was found in greater numbers in 2018 than in recent years.

Clearly, recent increases in SAV provide refuge and additional spawning habitat for Banded Killifish and Sunfish. Analysis shows that White Perch dominance was mainly indicative of the community present when there was no SAV; increased abundances of Bay Anchovy indicative for the period with some SAV; and Banded Killifish and Largemouth Bass indicative of the period when SAV beds were expansive. In 2017 seine collections were dominated by Banded Killifish. While the seine does not sample these SAV areas directly, the enhanced growth of SAV provides a large bank of Banded Killifish that spread out into the adjacent unvegetated shoreline areas and are sampled in the seines. The fyke nets that do sample the SAV areas directly documented a dominance of Sunfish and Banded Killifish in the SAV beds. In addition to SAV expansion, the invasive Blue Catfish may also have both direct (predation) and indirect (competition) effects, especially on species that occupy the same niche such as Brown Bullhead and Channel Catfish. Overall, these results indicate that the fish assemblage in Gunston Cove is dynamic and supports a diversity of commercial and recreational fishing activities.



The most direct indication we have of the status of river herring spawning populations is the anadromous study in Pohick and Accotink Creeks. Continued monitoring in years after this large spawning population was observed, will determine if this spawning season results in a successful year class, and if this is the first year of continued high river herring abundances. For the Gunston Cove watershed, 2018 was a highly productive year for Alewife, and above average for Blueback Herring (see figure to the left). We caught 1476 adult Alewife and 144 adult Blueback Herring; we have positively identified Blueback Herring in this survey since 2011. We also collected 17 Hickory Shad. These numbers are on the same order of magnitude as what we collected in 2015, which shows the anticipated return of the successful 2015 year-class has indeed happened, at least for Alewife. The estimated size of the spawning population of Alewife is close to ten thousand fishes in the Gunston Cove watershed in 2018. With a moratorium established in 2012 in Virginia, in conjunction with moratoria in other states connected to the north Atlantic at the same time or earlier, the order of magnitude increase in Alewife and Blueback Herring abundance three years after this occurrence (in 2015) could be a result of the moratoria. The moratoria prohibit the capture and/or possession of river herring (Alewife and Blueback Herring). The three-year delay coincides with the time it takes for river herring to mature, which means this is the first year a cohort has been protected under the moratoria for a complete life cycle. While it is too soon to tell what the long-term effects of the moratorium will be, and to what extent it affects the abundances in Potomac River tributaries, continued monitoring will determine whether some pattern of higher abundances is maintained in subsequent years. To truly capture Blueback Herring abundances we may need to extend the sampling season, since especially the larval densities seem to be highest late in our sampling period.

In summary, it is important to continue the data record that has been established to allow assessment of how the continuing increases in volume and improved efforts at wastewater treatment interact with the ecosystem as SAV increases and plankton and fish communities change in response. Furthermore, changes in the fish communities from the standpoint of habitat alteration by SAV and introductions of exotics like snakeheads and blue catfish need to be followed. 2018 has been highly instructive in showing how extreme rainfall conditions can alter the ecosystem and at least temporarily impede recovery.

Global climate change is becoming a major concern worldwide. Since 2000 a slight, but consistent increase in summer water temperature has been observed in the Cove which may reflect the higher summer air temperatures documented globally. Other potential effects of directional climate change remain very subtle and not clearly differentiated given seasonal and cyclic variability.

We recommend that:

1. Long term monitoring should continue. The revised schedule initiated in 2004 which focuses sampling in April through September has captured the major trends affecting water quality and the biota. The Gunston Cove study is a model for long term monitoring which is necessary to document the effectiveness of management actions. This process is sometimes called adaptive management and is recognized as the most successful approach to ecosystem management.
2. Two aspects of the program should be reviewed.
   a. In 2016 phytoplankton cell counts frequency was decreased from twice monthly to monthly as a cost-saving step. But it does result in some sampling dates not having phytoplankton data to go along with the other variables. If funds are available, we recommend reinstituting twice monthly phytoplankton counts.
   b. As nutrient concentrations have decreased in the river and cove due to management successes, we are now encountering a substantial number of samples which are below detection limits. This becomes a problem in data analysis. To date we have set "below dection limits" values at ½ the detection limit, but this becomes less defensable the greater the proportion of these values. This is particularly true of ammonia nitrogen. Since we understand that the County is not in a position to improve its detection limits we plan to present a supplemental proposal to the county to analyze ammonia in the water quality samples with a much lower detection limit.
3. The fyke nets have proven to be a successful addition to our sampling routine. Even though a small, non-quantitative sample is collected due to the passive nature of this gear, it provides us with useful information on the community within the submersed aquatic vegetation beds. Efficient use of time allows us to include these collections in a regular sampling day with little extra time or cost. We recommend continuing with this gear as part of the sampling routine in future years.
4. Anadromous fish sampling is an important part of this monitoring program and has gained interest now that the stock of river herring has collapsed, and a

moratorium on these taxa has been established in 2012. We recommend continued monitoring, and we plan to use the collections before and during the moratorium to help determine the effect of the moratorium. Our collections will also form the basis of a population model that can provide information on the status of the stock.

5. GMU's Potomac Environmental Research and Education Center instituted a continuous water quality monitoring site at Pohick Bay marina in May 2011. This program was suspended in 2014 due to ramp construction near the monitor, but we will consider reinstituting the program in 2017 should the County consider it valuable.
6. We have instituted some improvements to the benthic monitoring program including the quantitative characterization of larger (>5 mm) particles in the samples which we expect to help explain the variations we see in benthic communities between samples and station. For the moment we have put aside the effort to contruct a Benthic Index of Biotic Integrity (B-IBI) for the tidal Potomac River until we have looked at these relationships for a few years.

List of Abbreviations

BOD	Biochemical oxygen demand
cfs	cubic feet per second
DO	Dissolved oxygen
ha	hectare
l	liter
LOWESS	locally weighted sum of squares trend line
m	meter
mg	milligram
MGD	Million gallons per day
NS	not statistically significant
NTU	Nephelometric turbidity units
SAV	Submersed aquatic vegetation
SRP	Soluble reactive phosphorus
TP	Total phosphorus
TSS	Total suspended solids
um	micrometer
VSS	Volatile suspended solids
#	number

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THE ONGOING AQUATIC MONITORING PROGRAM

FOR THE GUNSTON COVE AREA

OF THE TIDAL FRESHWATER POTOMAC RIVER

2018

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to

Department of Public Works and Environmental Services
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INTRODUCTION

This section reports the results of the on-going aquatic monitoring program for Gunston Cove conducted by the Potomac Environmental Research and Education Center at George Mason University and Fairfax County's Environmental Monitoring Branch. This study is a continuation of work originated in 1984 at the request of the County's Environmental Quality Advisory Committee and the Department of Public Works. The original study design utilized 12 stations in Gunston Cove, the Potomac mainstem, and Dogue Creek. Due to budget limitations and data indicating that spatial heterogeneity was not severe, the study has evolved such that only two stations are sampled, but the sampling frequency has been maintained at semimonthly during the growing season. This sampling regime provides reliable data given the temporal variability of planktonic and other biological communities and is a better match to other biological sampling programs on the tidal Potomac including those conducted by the Maryland Department of Natural Resources and the District of Columbia. The 1984 report entitled "An Ecological Study of Gunston Cove – 1984" (Kelso et al. 1985) contained a thorough discussion of the history and geography of the cove. The reader is referred to that document for further details.

This work's primary objective is to determine the status of biological communities and the physico-chemical environment in the Gunston Cove area of the tidal Potomac River for evaluation of long-term trends. This will facilitate the formulation of well-grounded management strategies for maintenance and improvement of water quality and biotic resources in the tidal Potomac. Important byproducts of this effort are the opportunities for faculty research and student training which are integral to the educational programs at GMU.

The authors wish to thank the numerous individuals and organizations whose cooperation, hard work, and encouragement have made this project successful. We wish to thank the Fairfax County Department of Public Works and Environmental Services, Wastewater Planning and Monitoring Division, Environmental Monitoring Branch, particularly Juan Reyes and Shahram Mohsenin for their advice and cooperation during the study. Benny Gaines deserves recognition for field sample collection on days when Fairfax County collected independent samples. The entire analytical staff at the Noman Cole lab is gratefully acknowledged. The Northern Virginia Regional Park Authority facilitated access to the park and boat ramp. Without a dedicated group of field and laboratory workers this project would not have been possible. PEREC field and lab technician Laura Birsa deserves special recognition for day-to-day operations. Dr. Joris van der Ham headed up field fish collecting. Dr. Saiful Islam conducted phytoplankton counts. Thanks also go to C.J. Schlick, Beverly Bachman, Sammie Alexander, Chelsea Gray, Tabitha King, Kristen Reck, Jessie Melton, Rachel Kelmartin, Julia Czarnecki, Michael Cagle, Chris Bodner, Tanya Ramseyer, Chris Martin, Brian Kim, Alex Mott, Emily Bohr, and Sydney Frazier. Claire Buchanan served as a voluntary consultant on plankton identification. Honey Williams, Lisa Bair, Francina Osaria, Florencia Gutierrez, and Hillary Hamm were vital in handling personnel and procurement functions.

METHODS

A. Profiles and Plankton: Sampling Day

Sampling was conducted on a semimonthly basis at stations representing both Gunston Cove and the Potomac mainstem (Figures 1a,b). One station was located at the center of Gunston Cove (Station 7) and the second was placed in the mainstem tidal Potomac channel off the Belvoir Peninsula just north of the mouth of Gunston Cove (Station 9). Dates for sampling as well as weather conditions on sampling dates and immediately preceding days are shown in Table 1. Gunston Cove is located in the tidal freshwater section of the Potomac about 20 km (13 miles) downstream from Washington, DC.

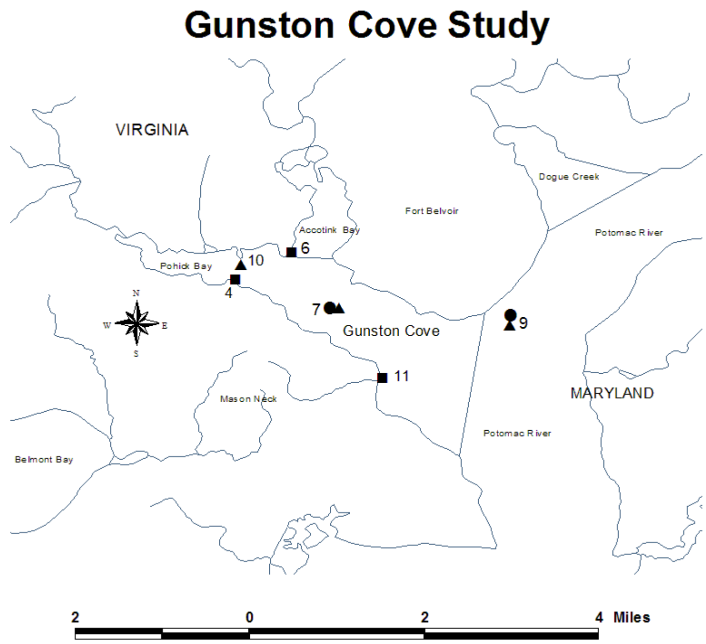


Figure 1a. Gunston Cove area of the Tidal Potomac River showing sampling stations. Circles (●) represent Plankton/Profile stations, triangles (▲) represent Fish Trawl stations, and squares (■) represent Fish Seine stations.

Figure 1b. Fish sampling stations including location and image of the fyke nets.

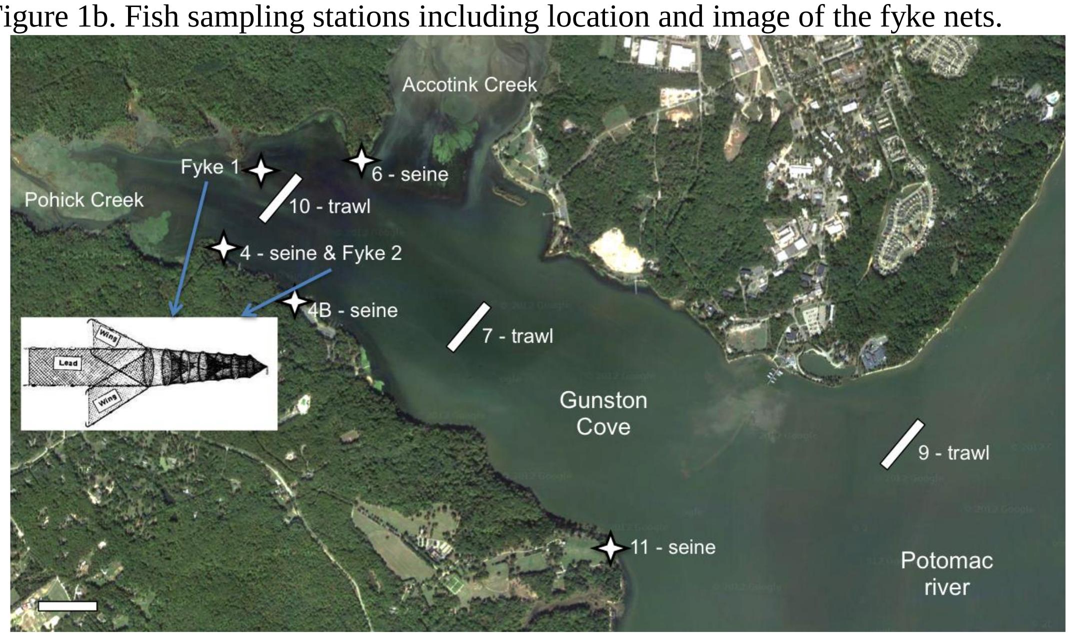


Table 1
Sampling Dates and Weather Data for 2018

	Type of Sampling					Avg Daily Temp (ºC)		Precipitation (cm)	
Date	G	F	T	S	Y	1-Day	3-Day	1-Day	3-Day
Apr 17			T	S	Y	7.2	11.5	0	5.11
Apr 25	G	F				16.1	15.9	0.81	1.98
May 8			T	S	Y	20.0	19.6	0	0
May 9	G					20.6	20.2	0	0
May 16		F*				21.7	23.1	2.08	6.91
May 22	G	F	T	S	Y	22.8	24.3	3.12	3.12
Jun 5	G		T	S	Y	22.8	20.7	0	4.19
Jun 11		F*				17.8	22.0	1.07	1.33
Jun 19	G	F	T	S	Y	30.0	28.5	2.84	2.84
Jul 3	G					31.7	27.8	T	T
Jul 10			T	S	Y	28.9	25.7	0	0
Jul 17	G	F				28.3	28.7	7.09	7.11
Jul 24		F*				26.1	25.6	0.81	4.39
Jul 27			T	S	Y	28.3	27.4	T	1.71
Aug 7	G		T	S	Y	28.3	28.3	0.30	0.77
Aug 14		F*				25.6	26.5	0	0.93
Aug 21	G	F	T	S	Y	25.6	25.7	6.25	6.26
Sep 4	G	F				30.6	29.4	T	T
Sep 19	G					26.7	25.7	0	3.76
Sep 21			T	S	Y	22.8	24.6	0.71	0.71
Sep 25		F*				23.9	20.2	0.25	2.79

Type of Sampling: B: Benthic, G: GMU profiles and plankton, F: nutrient and lab water quality by Fairfax County Laboratory, T: fish collected by trawling, S: fish collected by seining, Y: fish collected by fyke net. Except as indicated by asterisk, all samples collected by GMU personnel.
*Samples collected by Fairfax County Lab Personnel

Sampling was initiated at 10:30 am. Four types of measurements or samples were obtained at each station : (1) depth profiles of temperature, conductivity, dissolved oxygen, pH, and irradiance (photosynthetically active radiation) measured directly in the field; (2) water samples for GMU lab determination of chlorophyll *a* and phytoplankton species composition and abundance; (3) water samples for determination of nutrients, BOD, alkalinity, suspended solids, chloride, and pH by the Environmental Laboratory of the Fairfax County Department of Public Works and Environmental Services; (4) net sampling of zooplankton and ichthyoplankton.

Profiles of temperature, conductivity, dissolved oxygen, and pH were conducted at each station using a YSI 6600 datasonde. Measurements were taken at 0.3 m, 1.0 m, 1.5 m, and 2.0 m in the cove. In the river measurements were made with the sonde at depths of 0.3 m, 2 m, 4 m, 6 m, 8 m, 10 m, and 12 m. Meters were checked for calibration before and after sampling. Profiles of irradiance (photosynthetically active radiation, PAR) were collected with a LI-COR underwater flat scalar PAR probe. Measurements were taken at 10 cm intervals to a depth of 1.0 m. Simultaneous measurements were made with a terrestrial probe in air during each profile to correct for changes in ambient light if needed. Secchi depth was also determined. The readings of at least two crew members were averaged due to variability in eye sensitivity among individuals.

A 1-liter depth-composited sample was constructed from equal volumes of water collected at each of three depths (0.3 m below the surface, middepth, and 0.3 m off of the bottom) using a submersible bilge pump. A 100-mL aliquot of this sample was preserved immediately with acid Lugol's iodine for later identification and enumeration of phytoplankton. The remainder of the sample was placed in an insulated cooler with ice. A separate 1-liter sample was collected from 0.3 m using the submersible bilge pump and placed in the insulated cooler with ice for lab analysis of surface chlorophyll *a*. These samples were analyzed by Mason.

Separate 4-liter samples were collected monthly at each site from just below the surface (0.3 m) and near the bottom (0.3 m off bottom) at each site using the submersible pump. This water was promptly delivered to the nearby Fairfax County Environmental Laboratory for determination of nitrogen, phosphorus, BOD, TSS, VSS, pH, total alkalinity, and chloride.

Microzooplankton was collected by pumping 32 liters from each of three depths (0.3 m, middepth, and 0.3 m off the bottom) through a 44 µm mesh sieve. The sieve consisted of a 12-inch long cylinder of 6-inch diameter PVC pipe with a piece of 44 µm nitex net glued to one end. The 44 µm cloth was backed by a larger mesh cloth to protect it. The pumped water was passed through this sieve from each depth and then the collected microzooplankton was backflushed into the sample bottle. The resulting sample was treated with about 50 mL of club soda and then preserved with formalin containing a small amount of rose bengal to a concentration of 5-10%.

Macrozooplankton was collected by towing a 202 µm net (0.3 m opening, 2 m long) for 1 minute at each of three depths (near surface, middepth, and near bottom). Ichthyoplankton was sampled by towing a 333 µm net (0.5 m opening, 2.5 m long) for 2 minutes at each of the same depths. In the cove, the boat made a large arc during the tow while in the river the net was towed in a more linear fashion along the channel. Macrozooplankton tows were about 300 m and ichthyoplankton tows about 600 m. Actual distance depended on specific wind conditions and tidal current intensity and direction, but an attempt was made to maintain a constant slow forward speed through the water during the tow. The net was not towed directly in the wake of the engine. A General Oceanics flowmeter, fitted into the mouth of each net, was used to establish the exact towing distance. During towing the three depths were attained by playing out rope equivalent to about 1.5-2 times the desired depth. Samples which had obviously scraped bottom were discarded and the tow was repeated. Flowmeter readings taken before and after towing allowed precise determination of the distance towed and when multiplied by the area of the opening produced the total volume of water filtered.

Macrozooplankton and ichthyoplankton were backflushed from the net cup and immediately preserved. Rose bengal formalin with club soda pretreatment was used for macrozooplankton. Ichthyoplankton were preserved in 70% ethanol. Macrozooplankton was collected on each sampling trip; ichthyoplankton collections ended after July because larval fish were normally not found after this time.

Benthic macroinvertebrates were sampled using a petite ponar sampler at Stations 7 and 9. Triplicate samples were collected at each site on dates when water samples for Fairfax County lab analysis were not collected. The protocol in use for the past several years specified that the bottom samples were sieved on site through a 0.5 mm stainless steel sieve. Larger items like SAV, leaves, sticks, and empty shells were rinsed with tap water through the sieve and discarded. The smaller materials remaining on the 0.5 mm sieve were then preserved with rose bengal formalin.

In an effort to understand the role of larger particulate material in structuring the benthic community, a new field protocol was instituted in August 2018. Samples were first sieved through a 5 mm coarse mesh to remove larger items mentioned above. Materials remaining on the 5 mm sieve were thoroughly washed in the field and the material retained on the sieve was transferred to a zip lock bag and placed on ice for further processing in the lab.

Samples were delivered to the Fairfax County Environmental Services Laboratory by 2 pm on sampling day and returned to GMU by 3 pm. At GMU 10-15 mL aliquots of both depth-integrated and surface samples were filtered through 0.45 µm membrane filters (Gelman GN-6 and Millipore MF HAWP) at a vacuum of less than 10 lbs/in^2 for chlorophyll a and pheopigment determination. During the final phases of filtration, 0.1 mL of $MgCO_3$ suspension (1 g/100 mL water) was added to the filter to prevent premature acidification. Filters were stored in 20 mL plastic scintillation vials in the lab freezer for later analysis. Seston dry weight and seston organic weight were measured by filtering 200-400 mL of depth-integrated sample through a pretared glass fiber filter (Whatman 984AH).

Sampling day activities were normally completed by 5:30 pm.

B. Profiles and Plankton: Follow-up Analyses

Chlorophyll *a* samples were extracted in a ground glass tissue grinder to which 4 mL of dimethyl sulfoxide (DMSO) was added. The filter disintegrated in the DMSO and was ground for about 1 minute by rotating the grinder under moderate hand pressure. The ground suspension was transferred back to its scintillation vial by rinsing with 90% acetone. Ground samples were stored in the refrigerator overnight. Samples were removed from the refrigerator and centrifuged for 5 minutes to remove residual particulates.

Chlorophyll *a* concentration in the extracts was determined fluorometrically using a Turner Designs Model 10 field fluorometer configured for chlorophyll analysis as specified by the manufacturer. The instrument was calibrated using standards obtained from Turner Designs. Fluorescence was determined before and after acidification with 2 drops of 10% HCl. Chlorophyll *a* was calculated from the following equation which corrects for pheophytin interference:

$$\text{Chlorophyll } a\ (\mu g/L) = F_s R_s (R_b - R_a)/(R_s - 1)$$

where F_s=concentration per unit fluorescence for pure chlorophyll *a*
R_s=fluorescence before acid / fluorescence after acid for pure chlorophyll *a*
R_b=fluorescence of sample before acid
R_a=fluorescence of sample after acid

All chlorophyll analyses were completed within one month of sample collection.

Phytoplankton species composition and abundance was determined using the inverted microscope-settling chamber technique (Lund et al. 1958). Ten milliters of well-mixed algal sample were added to a settling chamber and allowed to stand for several hours. The chamber was then placed on an inverted microscope and random fields were enumerated. At least two hundred cells were identified to species and enumerated on each slide. Counts were converted to number per mL by dividing number counted by the volume counted. Biovolume of individual cells of each species was determined by measuring dimensions microscopically and applying volume formulae for appropriate solid shapes.

Microzooplankton and macrozooplankton samples were rinsed by sieving a well-mixed subsample of known volume and resuspending it in tap water. This allowed subsample volume to be adjusted to obtain an appropriate number of organisms for counting and for formalin preservative to be purged to avoid fume inhalation during counting. One mL subsamples were placed in a Sedgewick-Rafter counting cell and whole slides were analyzed until at least 200 animals had been identified and enumerated. A minimum of two slides was examined for each sample. References for identification were: Ward and Whipple (1959), Pennak (1978), and Rutner-Kolisko (1974). Zooplankton counts were converted to number per liter (microzooplankton) or per cubic meter (macrozooplankton) with the following formula:

Zooplankton (#/L or #/m^3) = $NV_s/(V_cV_f)$

where N = number of individuals counted
V_s = volume of reconstituted sample, (mL)
V_c = volume of reconstituted sample counted, (mL)
V_f = volume of water sieved, (L or m^3)

When the large cladoceran *Leptodora* was visible in a sample we used a modified method in which a know subsample was placed in a small petri dish and the entire number of *Leptodora* in this subsample were tallied using a dissecting microscope. These counts were converted to #/m^3 using the above equation.

Ichthyoplankton samples were sieved through a 333 µm sieve to remove formalin and then reconstituted in ethanol. Larval fish were picked from this reconstituted sample with the aid of a stereo dissecting microscope, and the total number of larval fish was counted. Identification of ichthyoplankton was made to family and further to genus and species where possible. The works of Hogue et al. (1976), Jones et al. (1978), Lippson and Moran (1974), and Mansueti and Hardy (1967) were used for identification. The number of ichthyoplankton in each sample was expressed as number per 10 m^3 using the following formula:

Ichthyoplankton (#/10m^3) = $10N/V$

where N = number ichthyoplankton in the sample
V = volume of water filtered, (m^3)

C. Adult and Juvenile Fish

Fishes were sampled by trawling at stations 7, 9, and 10, seining at stations 4, 4B, 6, and 11, and setting fyke nets at stations fyke 1 and fyke 2 (Figure 1a and b). For trawling, a try-net bottom trawl with a 15-foot horizontal opening, a ¾ inch square body mesh and a ¼ inch square cod end mesh was used. The otter boards were 12 inches by 24 inches. Towing speed was 2-3 miles per hour and tow length was 5 minutes. In general, the trawl was towed across the axis of the cove at stations 7 and 10 and parallel to the channel at station 9. The direction of tow should not be crucial. Dates of sampling and weather conditions are found in Table 1. Due to extensive SAV cover, station 10 could not be sampled in June, July, August and September of 2017.

Seining was performed with seine net that was 50 feet long, 4 feet high, and made of knotted nylon with a ¼ inch square mesh. The seining procedure was standardized as much as possible. The net was stretched out perpendicular to the shore with the shore end in water no more than a few inches deep. The net was then pulled parallel to the shore for a distance of 100 feet by a worker at each end moving at a slow walk. Actual distance was recorded if in any circumstance it was lower than 100 feet. At the end of the prescribed distance, the offshore end of the net was swung in an arc to the shore and the net pulled up on the beach to trap the fish. Dates for seine sampling were generally the same as those for trawl sampling. 4B was added to the sampling stations since 2007 because extensive SAV growth interferes with sampling station 4 in late summer. Due to extensive SAV cover, station 4 could not be sampled in July, August and September of 2017.

Due to the permanent recovery of the SAV cover in station 4 and station 10, we adjusted our sampling regime in 2012, and have continued with this approach since then. Fyke nets are now set in station fyke 1 (near trawl station 10) and station fyke 2 (near seine station 4) during the entire sampling season. Setting fyke nets when seining and trawling is still possible will allow for gear comparison. Fyke nets were set within the SAV to sample the fish community that uses the SAV cover as habitat. Moving or discontinuing the trawl and seine collections when sampling with those gear types becomes impossible may underrepresent the fish community that lives within the dense SAV cover. Fyke nets are set for 5 hours to passively collect fish. The fyke nets have 5 hoops, a 1/4 inch mesh size, 16 feet wings and a 32 feet lead. Fish enter the net by actively swimming and/or due to tidal motion of the water. The lead increases catch by capturing the fish swimming parallel to the wings (see insert Figure 1b). Due to logistical issue, we did not set the fyke nets in April 2017.

After collection with various gear types, the fishes were measured for standard length to the nearest mm. Standard length is the distance from the front tip of the snout to the end of the vertebral column and base of the caudal fin. This is evident in a crease perpendicular to the axis of the body when the caudal fin is pulled to the side.

If the identification of the fish was not certain in the field, the specimen was preserved in 70% ethanol and identified later in the lab. Identification was based on characteristics in dichotomous keys found in several books and articles, including Jenkins and Burkhead (1983), Hildebrand and Schroeder (1928), Loos et al (1972), Dahlberg (1975), Scott and Crossman (1973), Bigelow and Schroeder (1953), Eddy and Underhill (1978), Page and Burr (1998), and Douglass (1999).

D. Submersed Aquatic Vegetation

Data on coverage and composition of submersed aquatic vegetation (SAV) were obtained from the SAV webpage of the Virginia Institute of Marine Science (http://www.vims.edu/bio/sav). Information on this web site was obtained from aerial photographs near the time of peak SAV abundance as well as ground surveys which were used to determine species composition. SAV abundances were also surveyed on August 29. As the research vessel slowly transited the cove, a weighted garden rake was dragged for 10-15 seconds along the bottom and retrieved. Adhering plants were identified and their relative abundance determined. About 40 such measurements were made on that date.

E. Benthic Macroinvertebrates

In the laboratory, materials collected on the 5 mm sieve for each sample were sorted into several groups: SAV, leaves/sticks/wood, shells. Each group was them dried and weighed separately. This was completed within 48 hours of sample collection

In the laboratory materials collected on the 0.5 mm sieve were rinsed with tap water through a 0.5 mm sieve to remove formalin preservative and resuspended in tap water. All organisms were picked, sorted, identified and enumerated. Picked organisms were retained in ethanol/glycerine.

F. Data Analysis

Several data flows were merged for analysis. Water quality data emanating from the Noman Cole laboratory was used for graphs of both current year seasonal and spatial patterns and long term trends. Water quality, plankton, benthos and fish data were obtained from GMU samples. Data for each parameter were entered into spreadsheets (Excel or SigmaPlot) for graphing of temporal and spatial patterns for the current year. Long term trend analysis was conducted with Systat by plotting data for a given variable by year and then constructing a LOWESS trend line through the data. For water quality parameters the trend analysis was conducted on data from the warmer months (June-September) since this is the time of greatest microbial activity and greatest potential water quality impact. For zooplankton and fish all data for a given year were used. When graphs are shown with a log axis, zero values have been ignored in the trend analysis. JMP v8.0.1was used for fish graphs. Linear regression and standard parametric (Pearson) correlation coefficients were conducted to determine the statistical significance of linear trends over the entire period of record.

RESULTS

A. Climatic and Hydrologic Factors - 2017

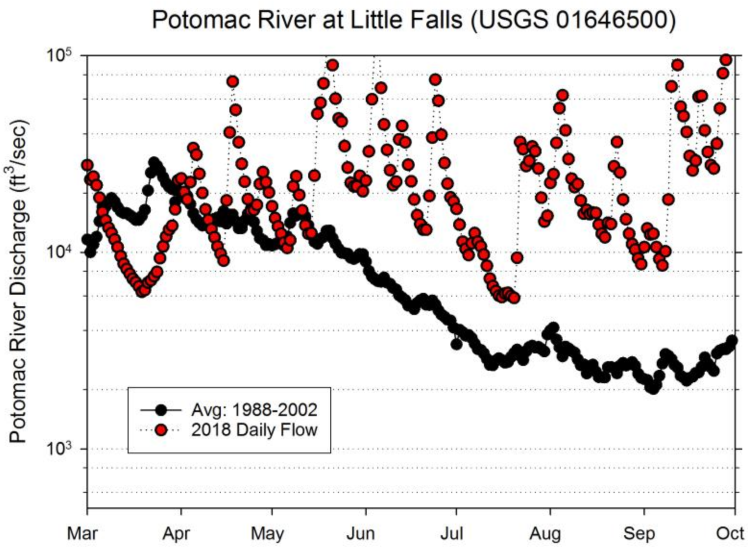
In 2018 temperature was below normal in March and April, but well above normal for the period May through September (Table 2). There were 37 days with maximum temperature above 32.2°C (90°F) in 2018 which is above the median number over the past decade. August was particularly warm in 2018 being 2°C higher than its normal average. Precipitation established some new records in 2018 with all months in the study period being above average and May, July and September receiving over twice their annual average rainfall. The largest daily rainfall total was 10.2 cm on July 21 which followed a 7.1 cm day on July 17. Another period of heavy precipitation was May 13-19 when substantial rainfall occurred every day and the total amounted to 15.2 cm. River and stream flows in 2018 were also well above average for most months in both the Potomac mainstem and in Accotink Creek indicating that the effects of the enhanced precipitation translate into higher flows both locally and regionally. Potomac River flow for each month between May and September was over twice the long-term average and in June and August, it was over four times the average. Accotink Creek was the most above average in July, over five times the long-term average.

Table 2. Meteorological Data for 2018. National Airport. Monthly Summary.

MONTH	Air Temp (°C)		Precipitation (cm)	
March	6.4	(8.1)	4.9	(9.1)
April	12.7	(13.4)	9.1	(7.0)
May	22.4	(18.7)	22.2	(9.7)
June	24.6	(23.6)	13.2	(8.0)
July	27.1	(26.2)	24.7	(9.3)
August	27.2	(25.2)	13.2	(8.7)
September	24.2	(21.4)	24.7	(9.6)
October	17.0	(14.9)	7.8	(8.2)

Table 3. Monthly mean discharge at USGS Stations representing freshwater flow into the study area. (+) 2018 month > 2x Long Term Avg. (-) 2018 month < ½ Long Term Avg.

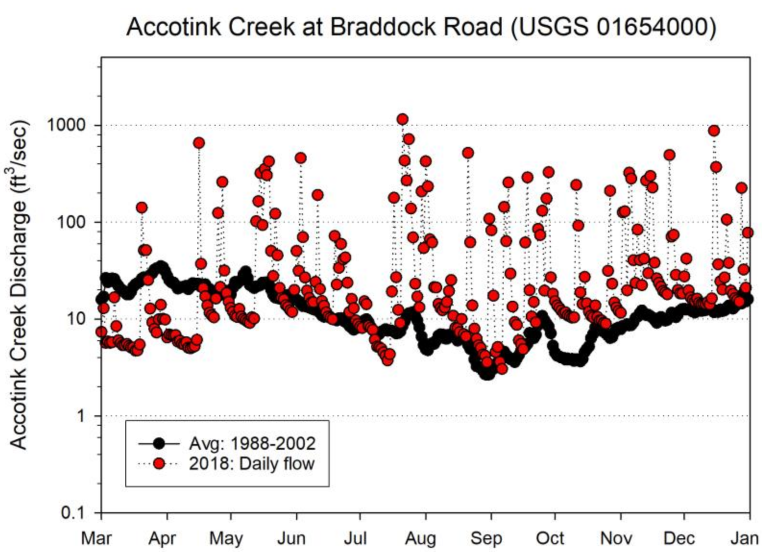
	Potomac River at Little Falls (cfs)		**Accotink Creek at Braddock Rd (cfs)**	
	2018	**Long Term Avg.**	**2018**	**Long Term Avg.**
March	12600	23600	15.3 (-)	42
April	23746	20400	45.0	36
May	33622 (+)	15000	72.8 (+)	34
June	38900 (+)	9030	45.4	28
July	14833 (+)	4820	111.0 (+)	22
August	21809 (+)	4550	55.9 (+)	22
September	46083 (+)	5040	63.8 (+)	27
October		5930	29.9	19



In a tidal freshwater system like the Potomac River, river flow entering from upstream is important in maintaining freshwater conditions and also serves to bring in dissolved and particulate substances from the watershed. High freshwater flows may also flush planktonic organisms downstream and bring in suspended sediments that decrease water clarity. The volume of river flow per unit time is referred to as "river discharge" by hydrologists. Note the long-term seasonal pattern of higher discharges in winter and spring and lower discharges in summer and fall.

Figure 2. Mean Daily Discharge: 2018. Potomac River at Little Falls (USGS Data). Month tick is at the beginning of the month.

These same patterns were seen in the graphs of daily river flow when compared to long-term averages (Figures 2 and 3). The long-term average shows a steadily decreasing trend from April through September. In 2018 this decline was not observed and river flow remained 2 to 10 times the long term mean for the entire study period. Of note is the minimum in river flow observed in early and mid-July in 2018 which was still higher than the long-term average. On many dates in 2018 Accotink Creek flow was 1-2 orders of magnitude greater than long term average.



In the Gunston Cove region of the tidal Potomac, freshwater discharge is occurring from both the major Potomac River watershed upstream (measured at Little Falls) and from immediate tributaries. The cove tributary for which stream discharge is available is Accotink Creek. Accotink Creek delivers over half of the stream water which directly enters the cove. While the gauge at Braddock Road only covers the upstream part of the watershed it is probably representative.

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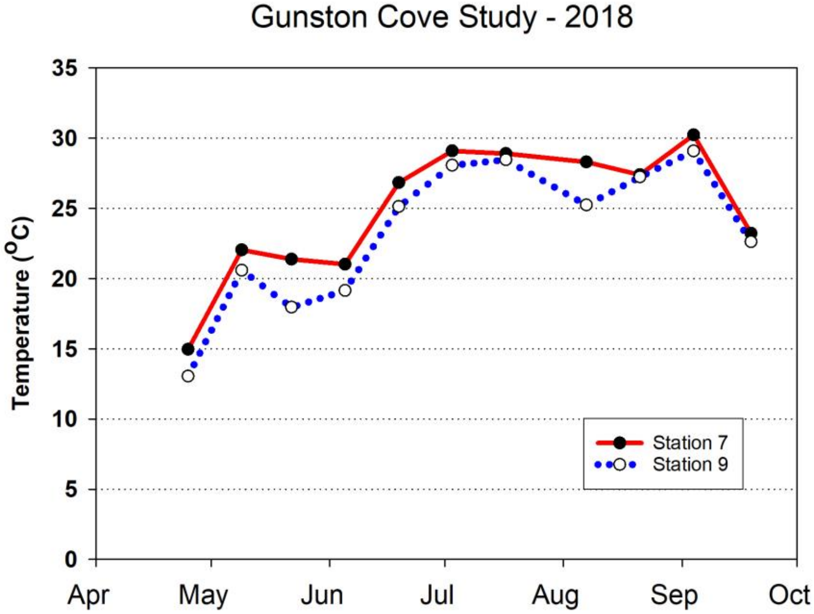
Figure 3. Mean Daily Discharge: 2018. Accotink Creek at Braddock Road (USGS Data).

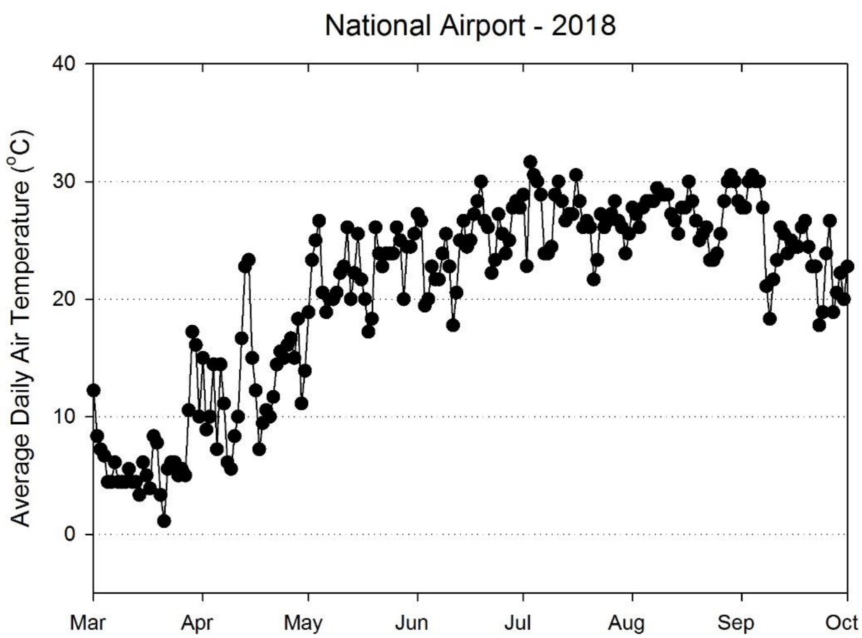
B. Physico-chemical Parameters – 2018



Water temperature is an important factor affecting both water quality and aquatic life. In a well-mixed system like the tidal Potomac, water temperatures are generally fairly uniform with depth.
In a shallow mixed system such as the tidal Potomac, water temperature often closely tracks daily changes in air temperature.

Figure 4. Water Temperature (°C). GMU Field Data. Month tick is at first day of month.

In 2018, water temperature followed the typical seasonal pattern at both sites with the exception of a marked cooling in late May (Figure 4). Both sites were between 25°C and 30°C throughout July and August the perod of highest air tremperatures (Figure 5). For most of the summer, the two stations showed very similar water temperatures with Station 7 generally slightly higher.



Mean daily air temperature (Figure 5) was a good predictor of water temperature (Figure 4). Variations in daily air temperature were more pronounce in the spring than in the summer.

Figure 5. Average Daily Air Temperature (°C) at Reagan National Airport.

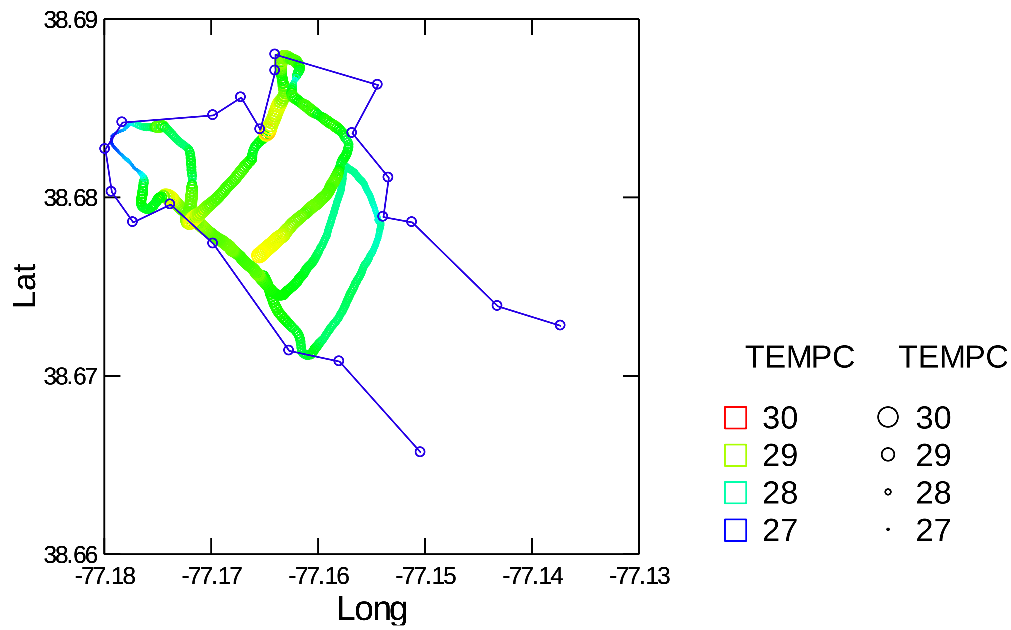


Figure 6. Temperature (ºC) observed in transects across Gunston Cove during data mapping cruise on August 14, 2018.

Temperature and Specific Conductance were measured during data mapping cruise on August 14, 2018 to assess spatial patterns in Gunston Cove. Temperature varied little across the cove (Figure 6). Specific conductance, on the other hand, showed a clear pattern with higher values in Pohick Bay gradually decreasing moving out into the body of Gunston Cove (Figure 7). Accotink Bay was also lower. Pattern suggests an effect of Noman Cole effluent which has higher specific conductance than Gunston Cove.

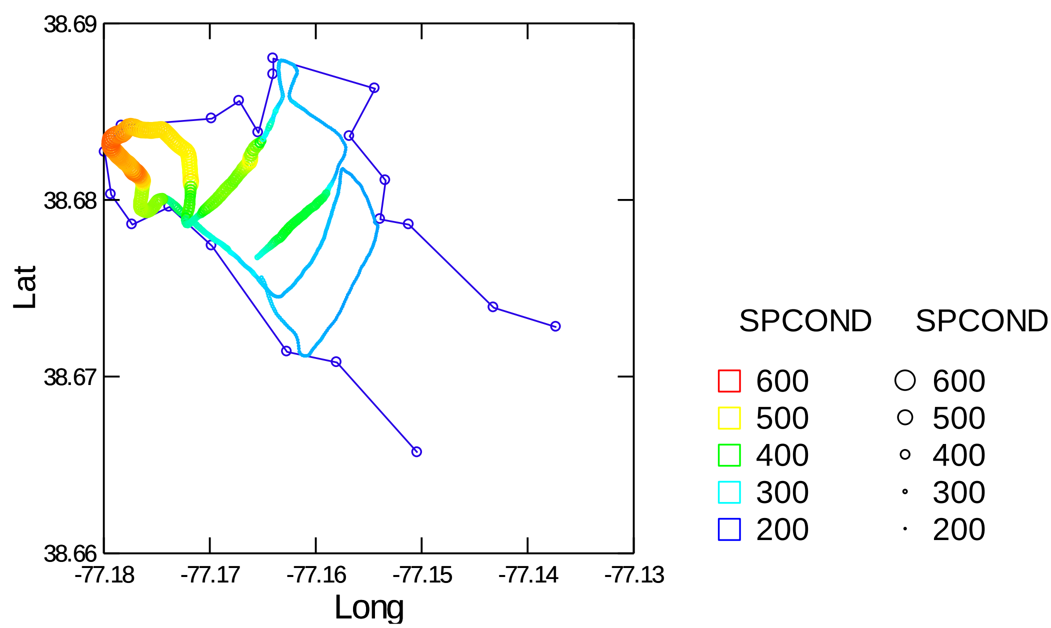
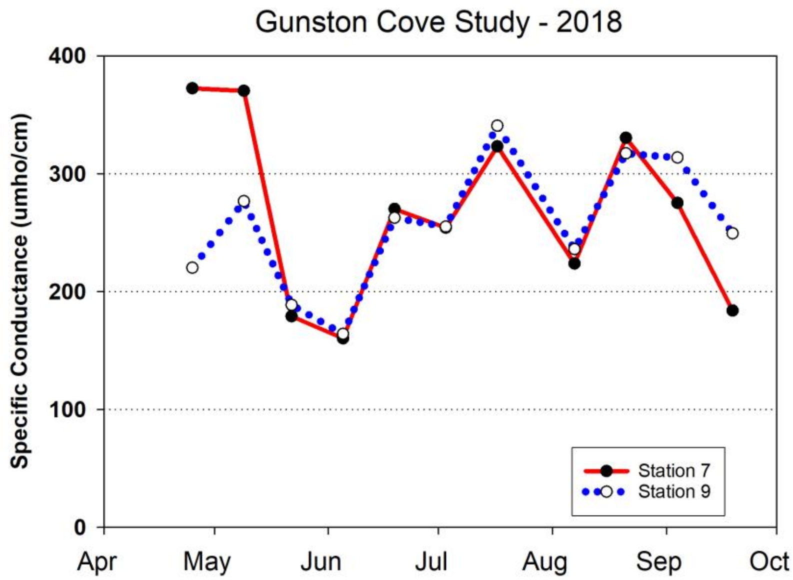


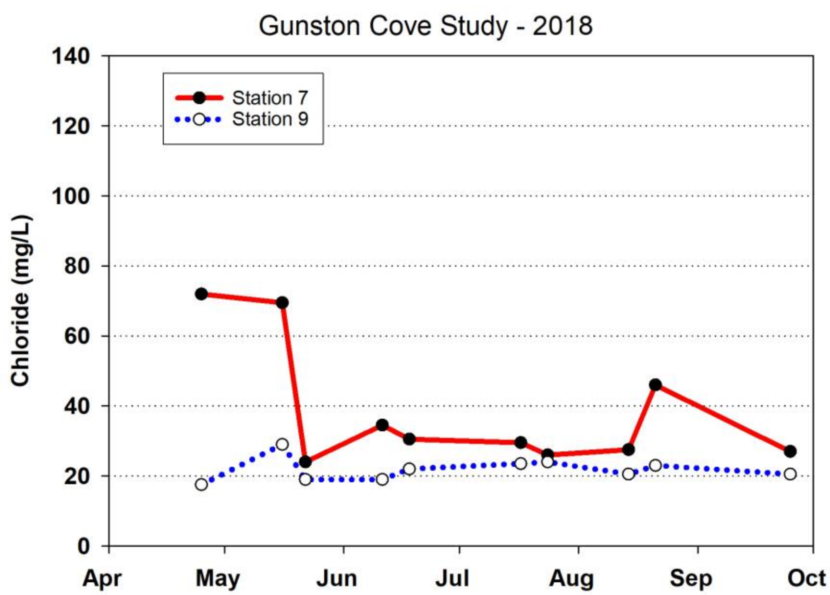
Figure 7. Specific Conductance (uS/cm) observed in transects across Gunston Cove during data mapping cruise on August 14, 2018.



Specific conductance measures the capacity of the water to conduct electricity standardized to 25°C. This is a measure of the concentration of dissolved ions in the water. In freshwater, conductivity is relatively low. Ion concentration generally increases slowly during periods of low freshwater inflow and decreases during periods of high freshwater inflow. In years of low freshwater inflow during the summer and fall, conductance may increase dramatically if brackish water from the estuary reaches the study area.

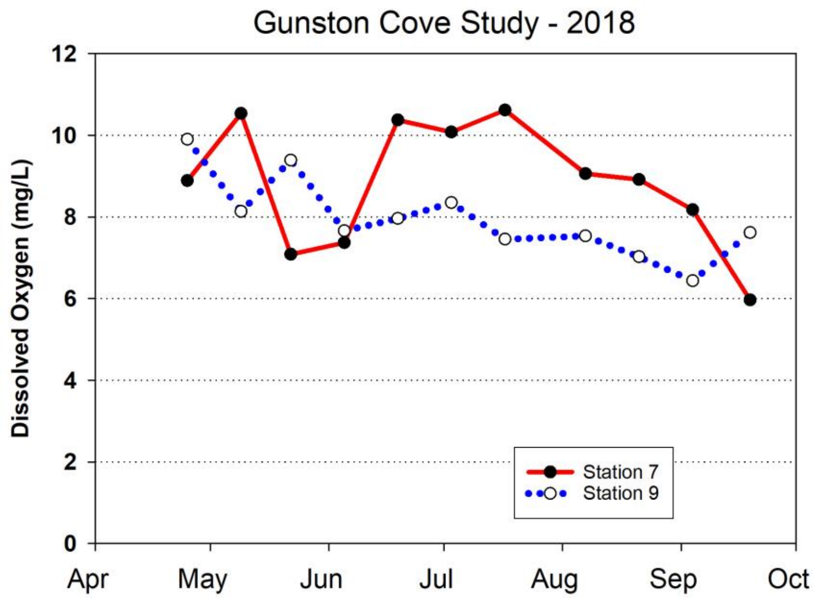
Figure 8. Specific Conductance (uS/cm). GMU Field Data. Month tick is at first day of month.

Specific conductance was elevated in late April and early May, but declined markedly in late May and early June and then again in early August (Figure 8). During most of the year there was little difference between stations. Chloride ion was markedly higher at Station 7 in late April and May, but was similar at both stations and fairly constant for the rest of the (Figure 9).



Chloride ion (Cl-) is a principal contributor to conductance. Major sources of chloride in the study area are sewage treatment plant discharges, road salt, and brackish water from the downriver portion of the tidal Potomac. Chloride concentrations observed in the Gunston Cove area are very low relative to those observed in brackish, estuarine, and coastal areas of the Mid-Atlantic region. Chloride often peaks markedly in late summer or fall when brackish water from down estuary may reach the cove as freshwater discharge declines.

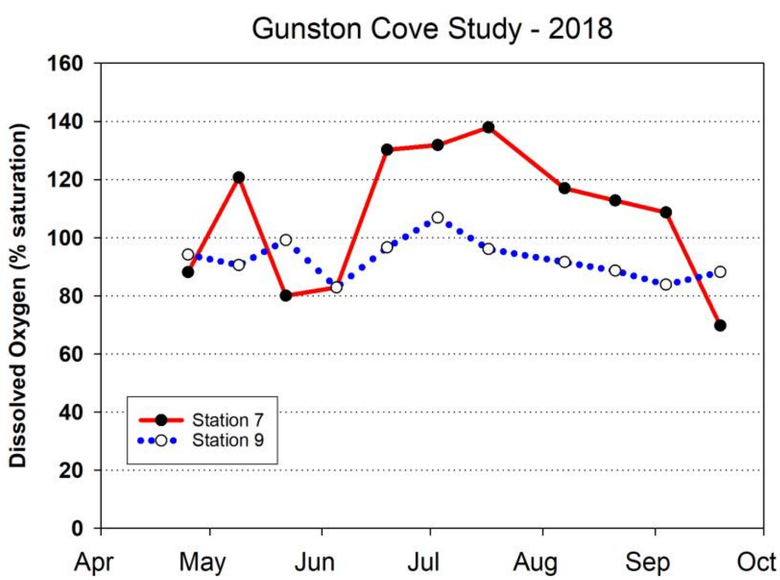
Figure 9. Chloride (mg/L). Fairfax County Lab Data. Month tick is at first day of month.



Oxygen dissolved in the water is required by freshwater animals for survival. The standard for dissolved oxygen (DO) in most surface waters is 5 mg/L. Oxygen concentrations in freshwater are in balance with oxygen in the atmosphere, but oxygen is only weakly soluble in water so water contains much less oxygen than air. This solubility is determined by temperature with oxygen more soluble at low temperatures.

Figure 10. Dissolved Oxygen (mg/L). GMU Field Data. Month tick is at first day of month.

Dissolved oxygen showed substantial differences between the two stations for most of the year (Figure 10). On most dates the two sites diverged with Station 7 in Gunston Cove consistently exhibiting much higher values. Figure 11 shows that dissolved oxygen levels in the cove were often substantially above 100% indicating abundant photosynthesis by SAV and phytoplankton. In the river values were generally equal or less than 100% indicating lower photosynthesis and an excess of respiration. Lower values in the cove in late May and early June were probably due to input of stormwater and concomitant increase in TSS and decreased light availability for photosynthesizers.



The temperature effect on oxygen concentration can be removed by calculating DO as percent saturation. This allows examination of the balance between photosynthesis and respiration both of which also impact DO. Photosynthesis adds oxygen to the water while respiration removes it. Values above 120% saturation are indicative of intense photosynthesis while values below 80% reflect a preponderance of respiration or decomposition.

Figure 11. Dissolved Oxygen (% saturation). GMU Field Data. Month tick is at first day of month.

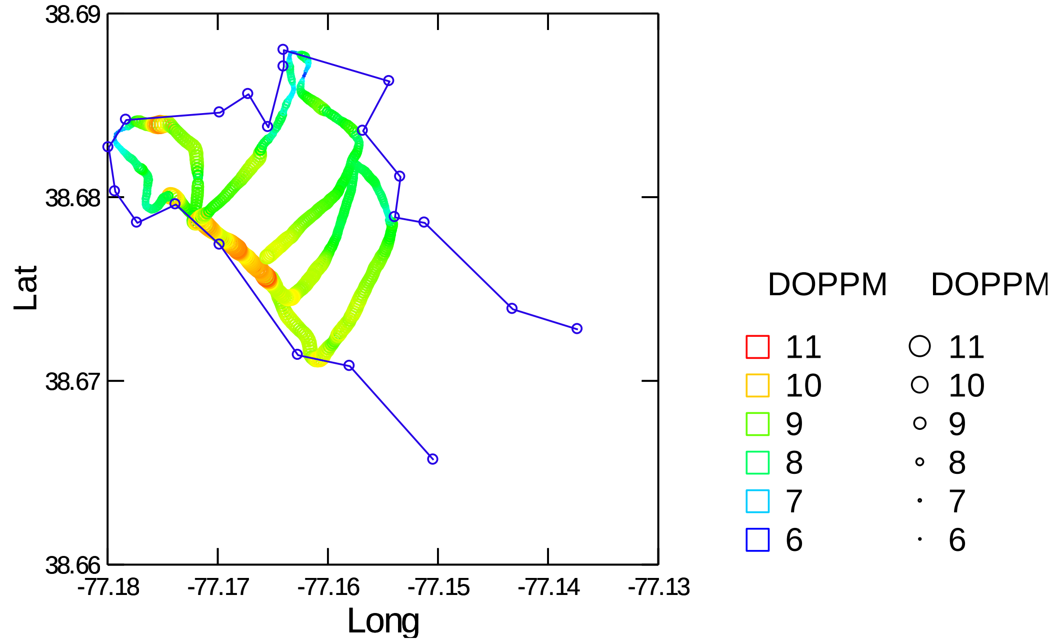


Figure 12. Dissolved Oxygen (mg/L) observed in transects across Gunston Cove during data mapping cruise on August 14, 2018.

Dissolved oxygen levels were substantially higher and were well above saturation along the south shore of Gunston Cove on August 14 (Figures 12&13). Values gradually decreased moving north and east in the cove and were also substantially lower in Accotink Bay and most of upper Pohick Bay. The supersaturated DO values indicated strong photosynthetic activity.

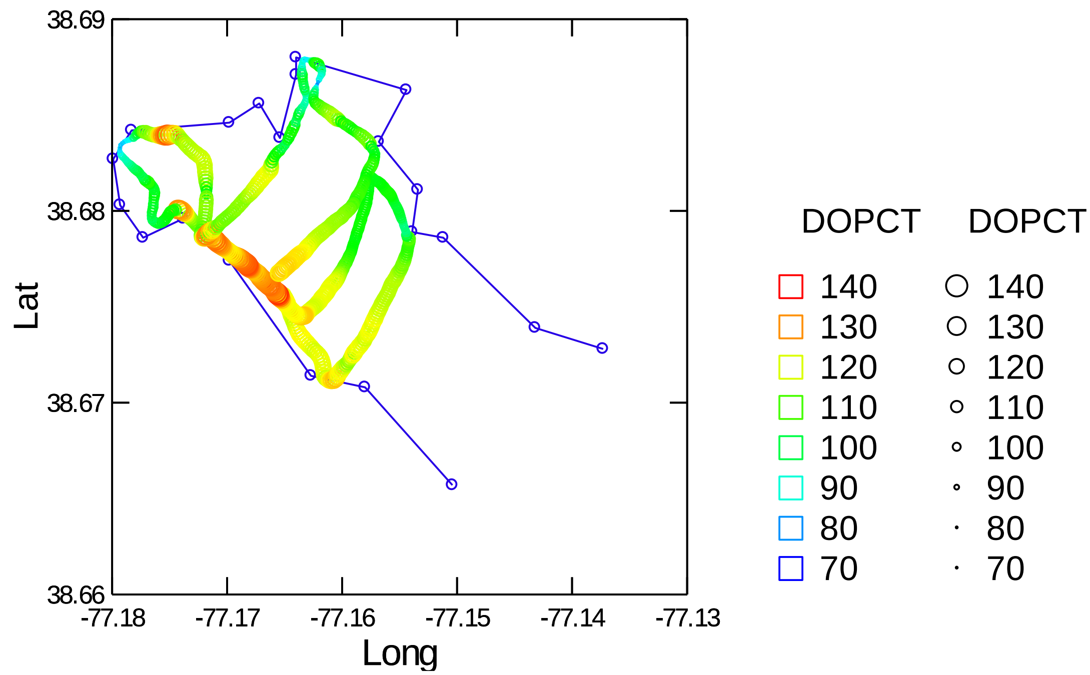
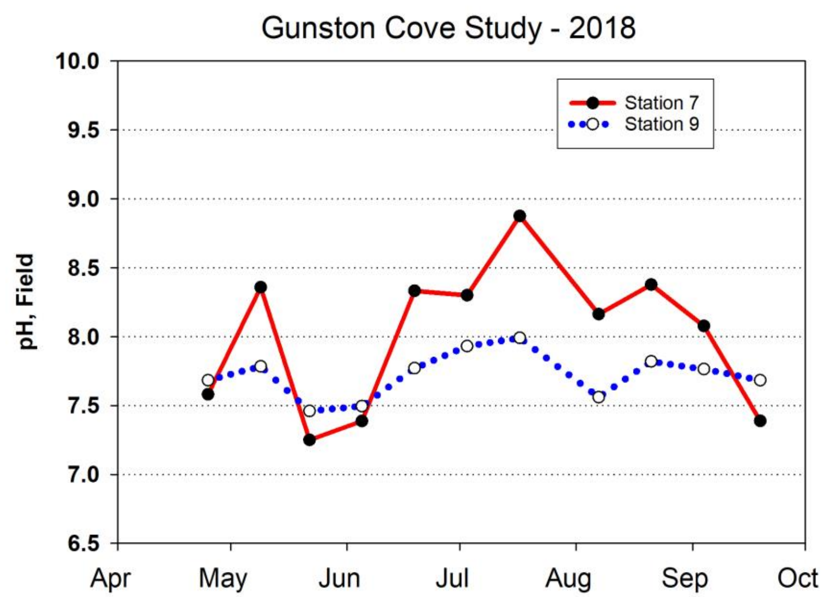


Figure 13. Dissolved Oxygen (% saturation) observed in transects across Gunston Cove during data mapping cruise on August 14, 2018.



pH is a measure of the concentration of hydrogen ions (H+) in the water. Neutral pH in water is 7. Values between 6 and 8 are often called circumneutral, values below 6 are acidic and values above 8 are termed alkaline. Like DO, pH is affected by photosynthesis and respiration. In the tidal Potomac, pH above 8 indicates active photosynthesis and values above 9 indicate intense photosynthesis.

Figure 14. pH. GMU Field Data. Month tick is at first day of month.

Field pH was consistently greater in the cove than in the river again reflecting differences in photosynthetic activity (Figure 14). Times of elevated pH generally corresponded to those in dissolved oxygen. This was also true comparing the spatial pattern of pH (Figure 15) with that of DO (Figure 13) and again is consistently with a photosynthetic activity effect. Given the paucity of SAV in 2018, this is probably due to phytoplankton.

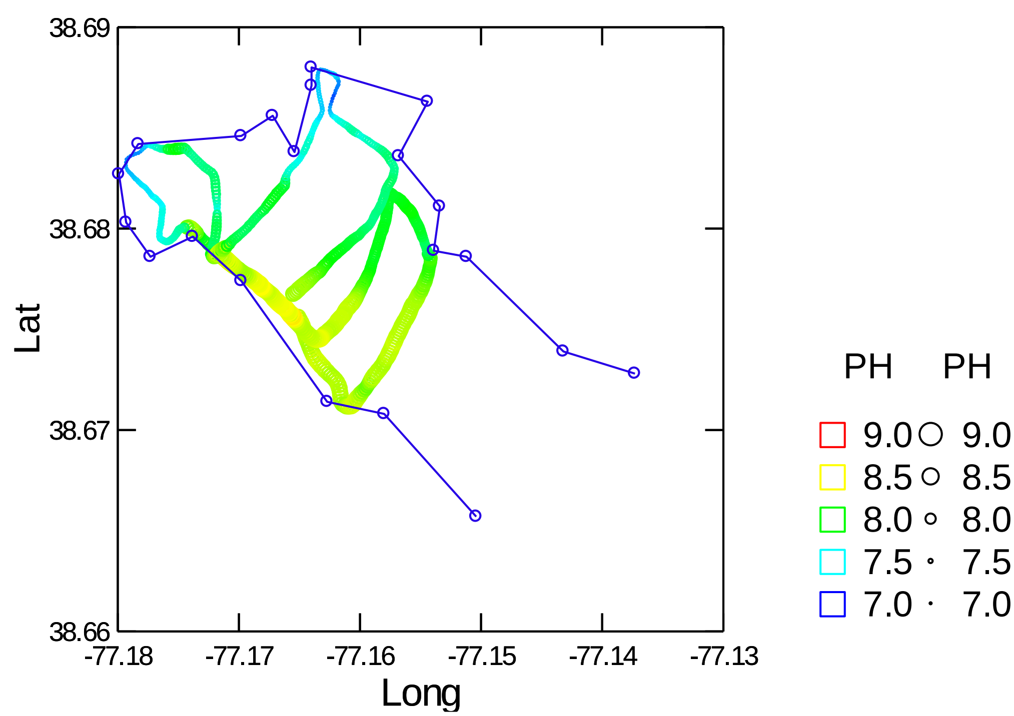
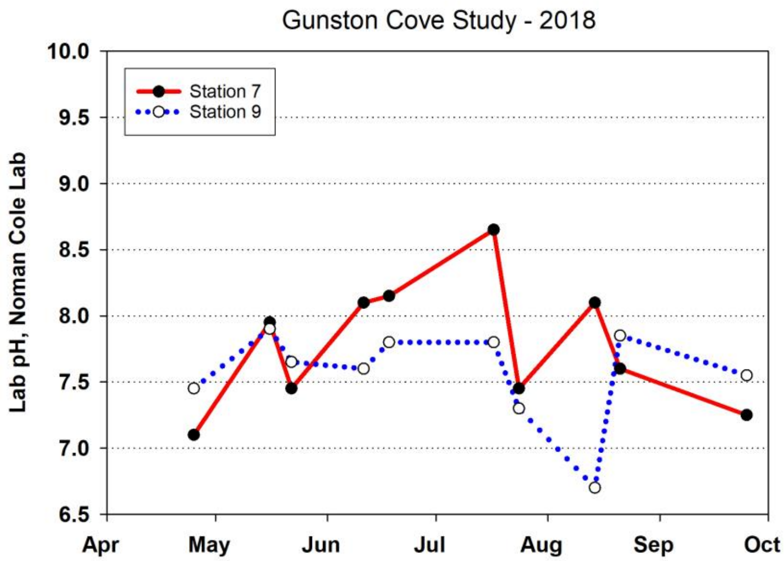


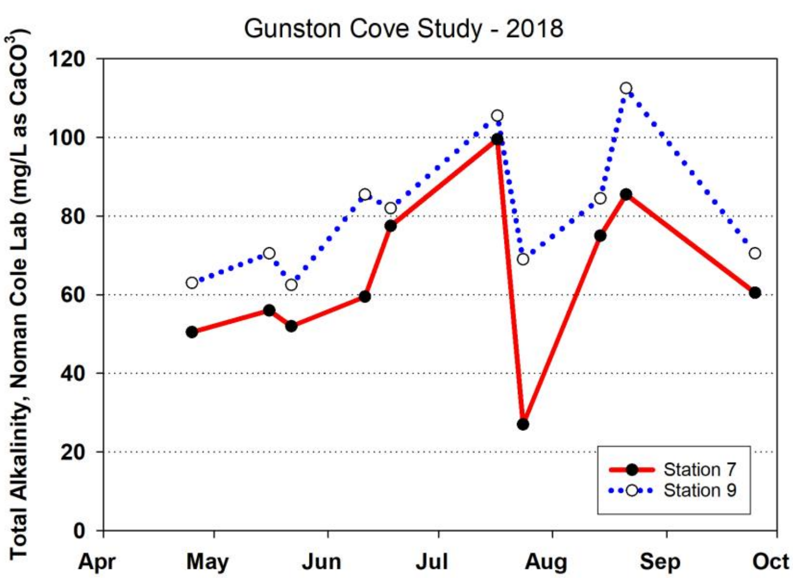
Figure 15. Field pH observed in transects across Gunston Cove during data mapping cruise on August 14, 2018.



pH may be measured in the field or in the lab. Field pH is more reflective of in situ conditions while lab pH is done under more stable and controlled laboratory conditions and is less subject to error. Newer technologies such as the Hydrolab and YSI sondes used in GMU field data collection are more reliable than previous field pH meters and should give results that are most representative of values actually observed in the river.

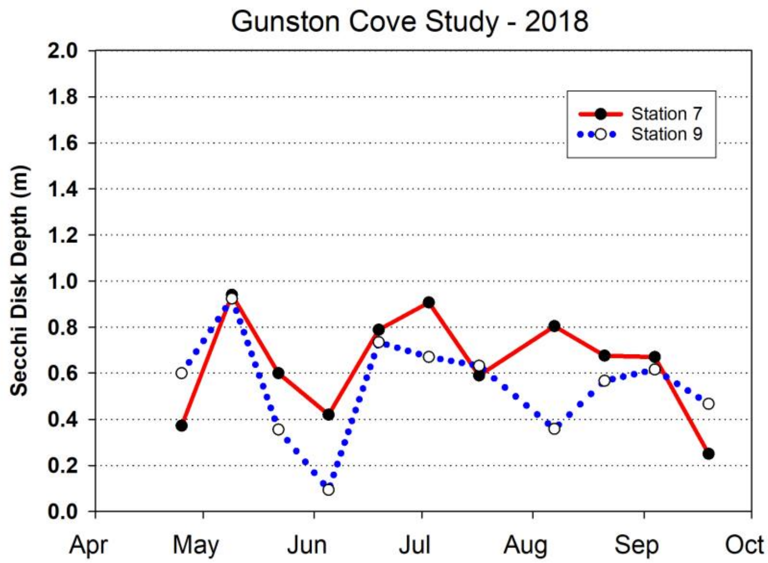
Figure 16. pH. Noman Cole Lab Data. Month tick is at first day of month.

Lab pH was collected less frequently, but generally showed similar patterns (Figure 16). Of note is that field pH showed a major decrease in the cove in late May and early June as was also observed in dissolved oxygen. Total alkalinity was consistently higher in the river than in the cove by about 5-10 units (Figure 17). A general seasonal increase in spring and summer was disrupted by a major decline at both stations in late July.



Total alkalinity measures the amount of bicarbonate and carbonate dissolved in the water. In freshwater this corresponds to the ability of the water to absorb hydrogen ions (acid) and still maintain a near neutral pH. Alkalinity in the tidal freshwater Potomac generally falls into the moderate range allowing adequate buffering without carbonate precipitation.

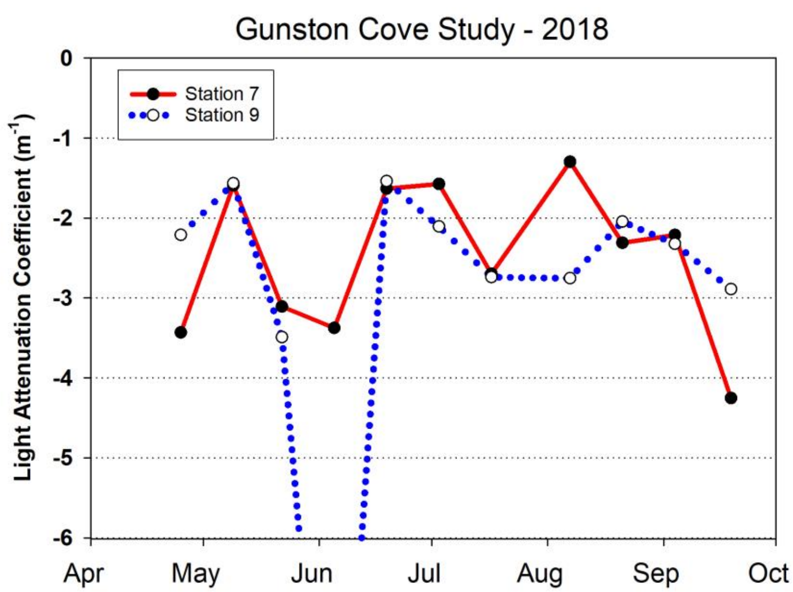
Figure 17. Total Alkalinity (mg/L as $CaCO_3$). Fairfax County Lab data. Month tick is at first day of month.



Secchi Depth is a measure of the transparency of the water. The Secchi disk is a flat circle or thick sheet metal or plywood about 6 inches in diameter which is painted into alternate black and white quadrants. It is lowered on a calibrated rope or rod to a depth at which the disk disappears. This depth is termed the Secchi Depth. This is a quick method for determining how far light is penetrating into the water column. Light is necessary for photosynthesis and thereby for growth of aquatic plants and algae.

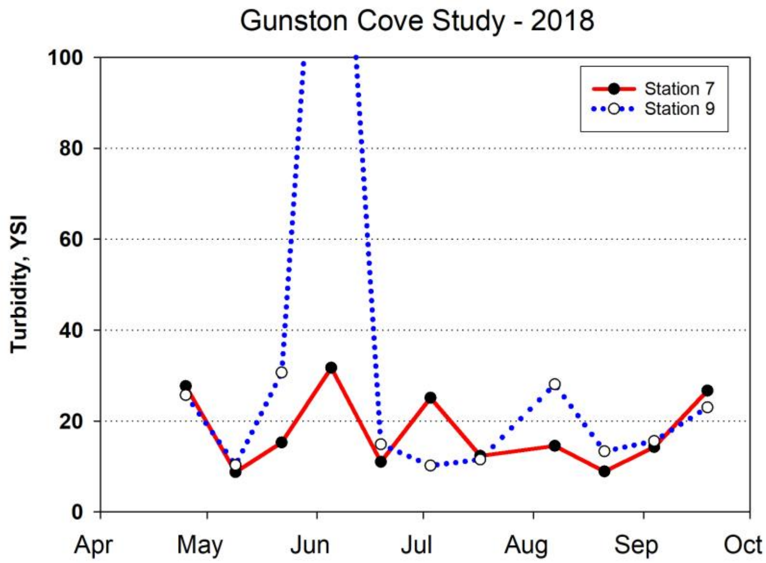
Figure 18. Secchi Disk Depth (m). GMU Field Data. Month tick is at first day of month.

Water clarity as reflected by Secchi disk transparency exhibited some major variations during the year. In contrast to recent years, transparency never exceeded 1 m and was very low in the river in early June following over 4 cm of rain and subsequent runoff into the river. Another dip was observed in the cove in late July also associated with rain and subsequent runoff (Figure 18). Light attenuation coefficient also showed the effects of storm runoff on the same dates as Secchi (Figure 19).



Light Attenuation is another approach to measuring light penetration. This is determined by measuring light levels at a series of depths starting near the surface. The resulting relationship between depth and light is fit to a semi-logarithmic curve and the resulting slope is called the light attenuation coefficient. This relationship is called Beer's Law. It is analogous to absorbance on a spectrophotometer. The greater the light attenuation, the faster light is absorbed with depth. More negative values indicate greater attenuation. Greater attenuation is due to particulate and dissolved material which absorbs and deflects light.

Figure 19. Light Attenuation Coefficient (m^{-1}). GMU Field Data. Month tick is at first day of month.



Turbidity is yet a third way of measuring light penetration. Turbidity is a measure of the amount of light scattering by the water column. Light scattering is a function of the concentration and size of particles in the water. Small particles scatter more light than large ones (per unit mass) and more particles result in more light scattering than fewer particles.

Figure 20. Turbidity (NTU). GMU Lab Data. Month tick is at first day of month.

Turbidity was less obviously affected than Secchi depth except on the early June date in the river (Figure 20). In the August datamapping cruise, turbidity was generally low except near the river where it was higher, similar to the higer levels observed in the river in the biweekly data (Figure 21)..

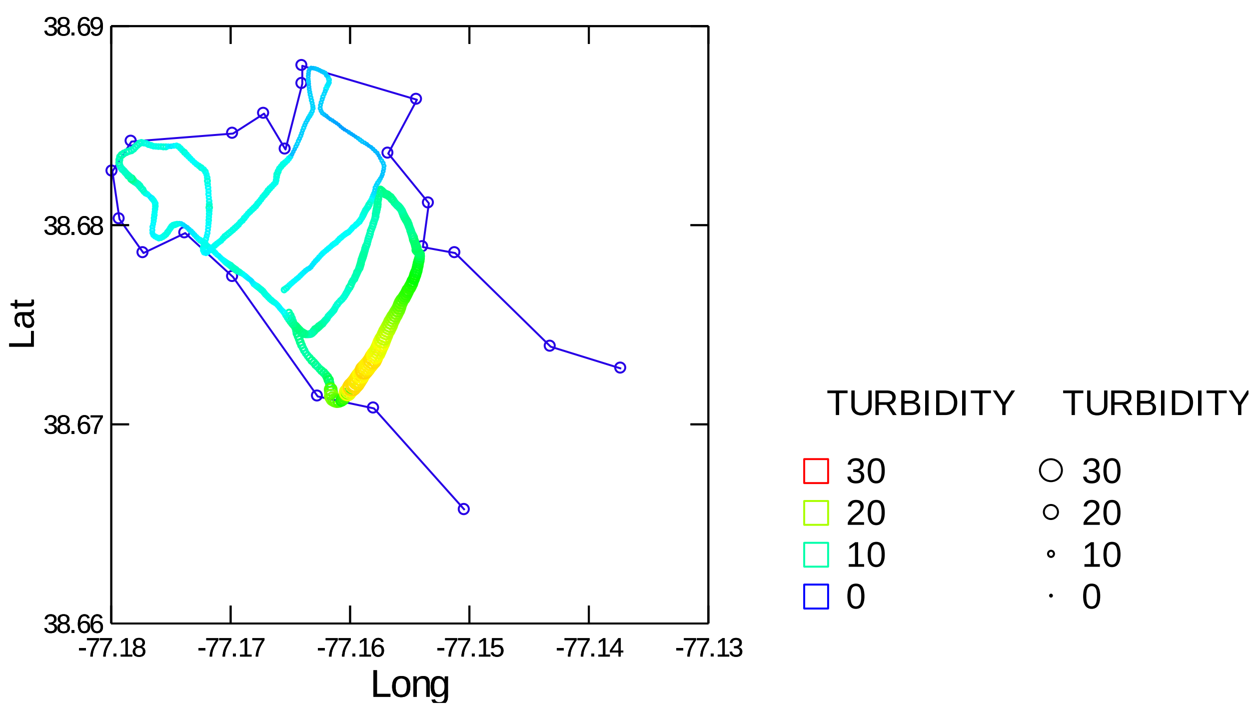
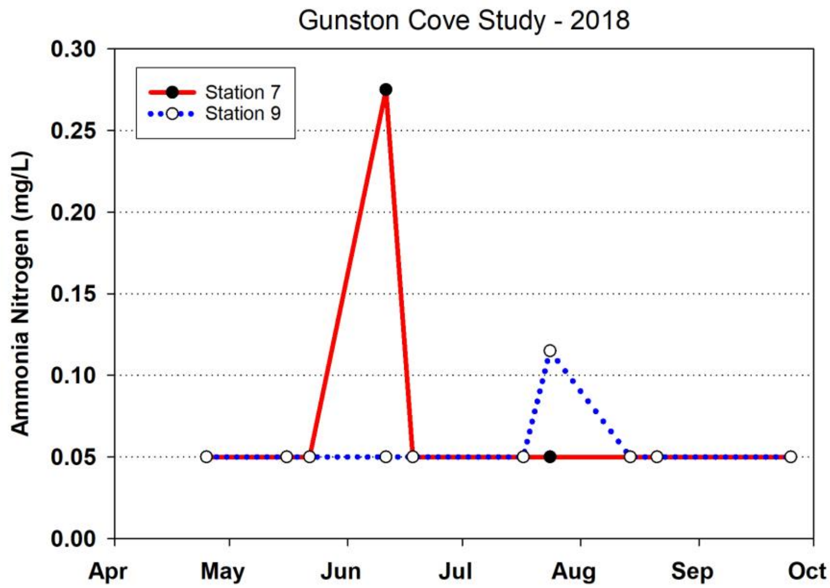


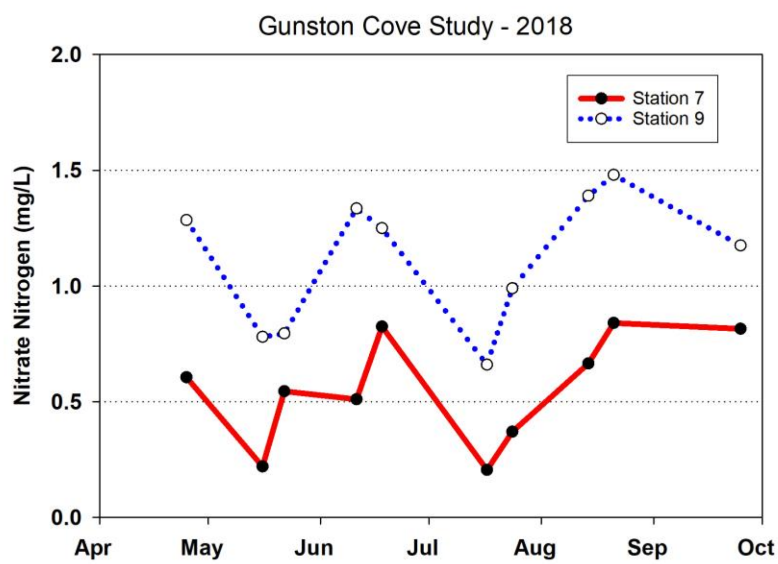
Figure 21. Turbidity (NTU) observed in transects across Gunston Cove during data mapping cruise on August 14, 2018.



Ammonia nitrogen measures the amount of ammonium ion (NH_4^+) and ammonia gas (NH_3) dissolved in the water. Ammonia nitrogen is readily available to algae and aquatic plants and acts to stimulate their growth. While phosphorus is normally the most limiting nutrient in freshwater, nitrogen is a close second. Ammonia nitrogen is rapidly oxidized to nitrate nitrogen when oxygen is present in the water.

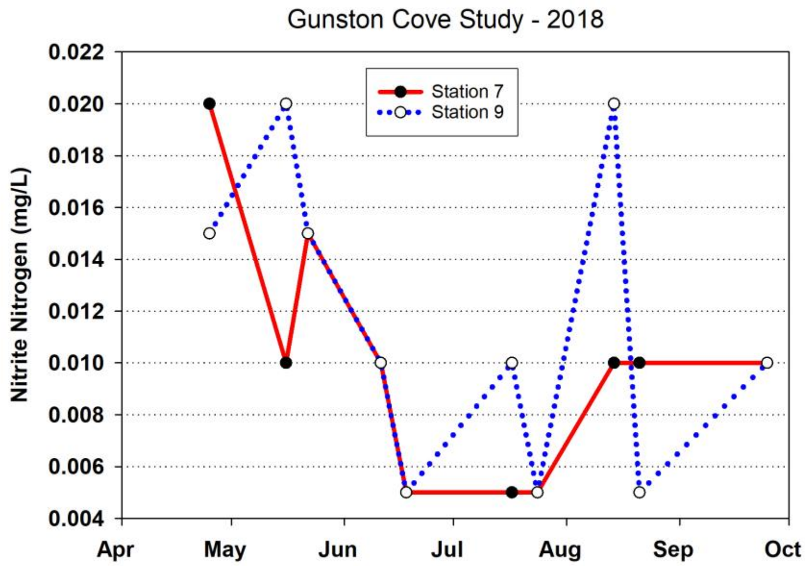
Figure 22. Ammonia Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection: 0.10 mg/L, LD values graphed as 0.05 mg/L)

Ammonia nitrogen was below detection limits in almost all samples reported in 2018 (Figure 22). Unfortunately, the detection limit at the Fairfax County Lab has increased substantially in the past two years from 0.01 mg/L to 0.1 mg/L. This has made it impossible to detect any further improvements in ammonia levels. The one date when dectable values were found in the cove was June 11. Nitrate nitrogen levels were consistently higher in the river than in the cove (Figure 23). The clear seasonal decline at Station 7 observed in most recent years was no apparent in 2018.



Nitrate Nitrogen refers to the amount of N that is in the form of nitrate ion (NO_3^-). Nitrate ion is the most common form of nitrogen in most well oxidized freshwater systems. Nitrate concentrations are increased by input of wastewater, nonpoint sources, and oxidation of ammonia in the water. Nitrate concentrations decrease when algae and plants are actively growing and removing nitrogen as part of their growth.

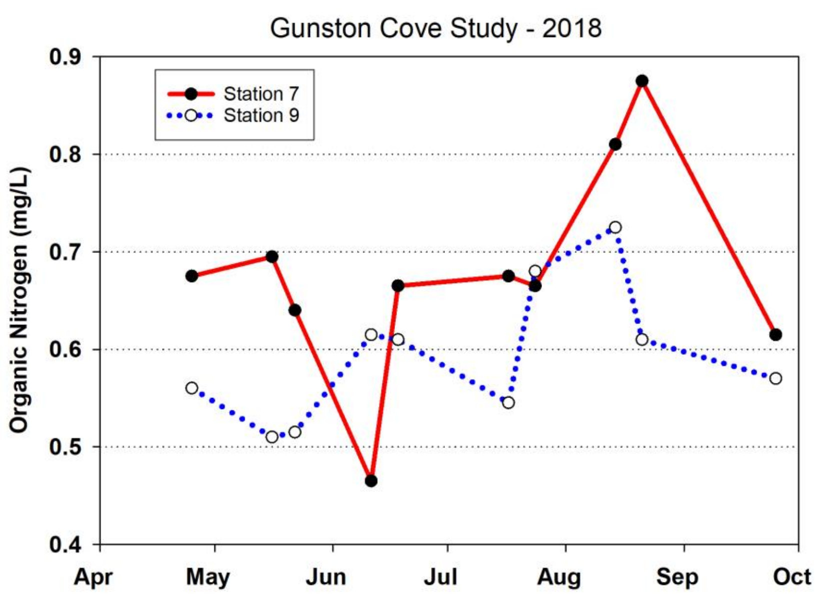
Figure 23. Nitrate Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection: 0.01 mg/L; LD values graphed as 0.005 mg/L)



Nitrite nitrogen consists of nitrogen in the form of nitrite ion (NO_2^-). Nitrite is an intermediate in the oxidation of ammonia to nitrate, a process called nitrification. Nitrite is usually in very low concentrations unless there is active nitrification.

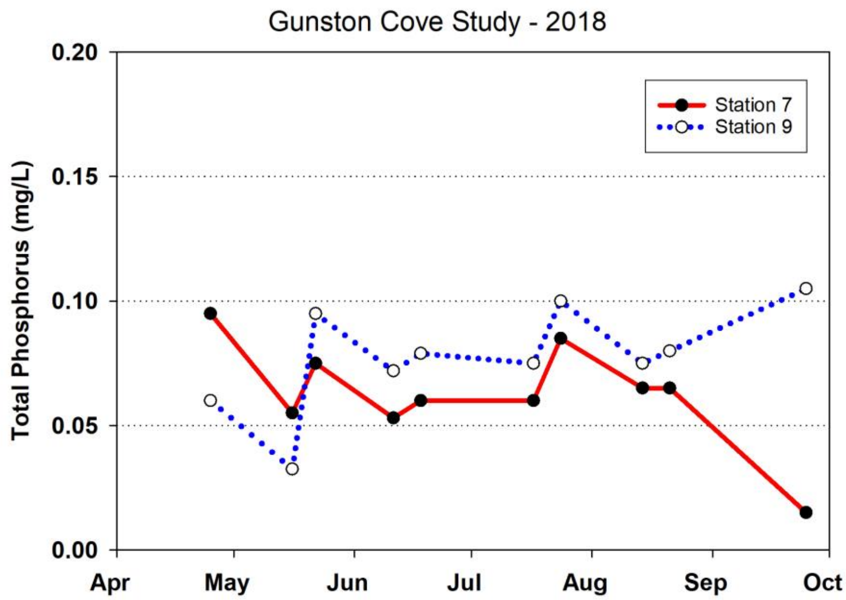
Figure 24. Nitrite Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (limit of detection = 0.01 mg/L).

Nitrite nitrogen was low and quite variable, but higher in the spring and fall in the cove (Figure 24). Organic nitrogen was quite variable in the cove with a peak in August and a minimum in June (Figure 25). In the river there appeared to be a seasonal increase through early August and a decline in September.



Organic nitrogen measures the nitrogen in dissolved and particulate organic compounds in the water. Organic nitrogen comprises algal and bacterial cells, detritus (particles of decaying plant, microbial, and animal matter), amino acids, urea, and small proteins. When broken down in the environment, organic nitrogen results in ammonia nitrogen. Organic nitrogen is determined as the difference between total Kjeldahl nitrogen and ammonia nitrogen.

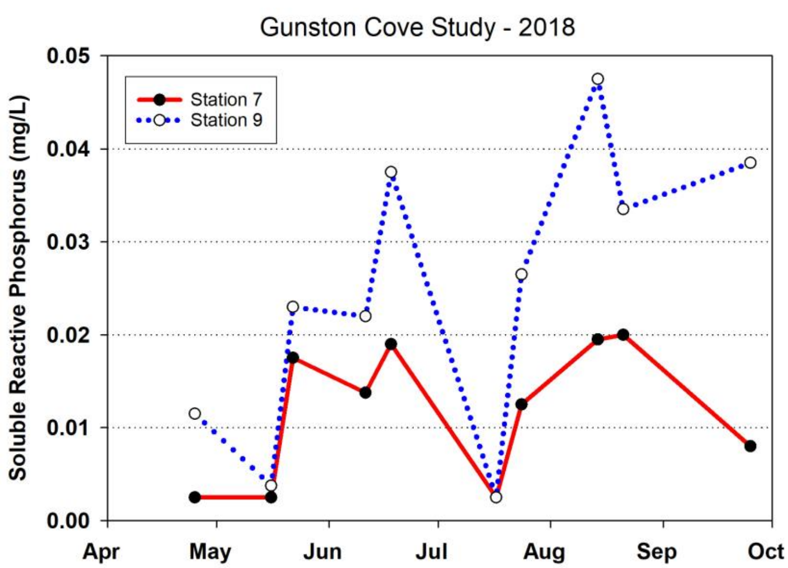
Figure 25. Organic Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month.



Phosphorus (P) is often the limiting nutrient in freshwater ecosystems. As such the concentration of P can set the upper limit for algal growth. Total phosphorus is the best measure of P availability in freshwater since much of the P is tied up in biological tissue such as algal cells. Total P includes phosphate ion (PO_4^{-3}) as well as phosphate inside cells and phosphate bound to inorganic particles such as clays.

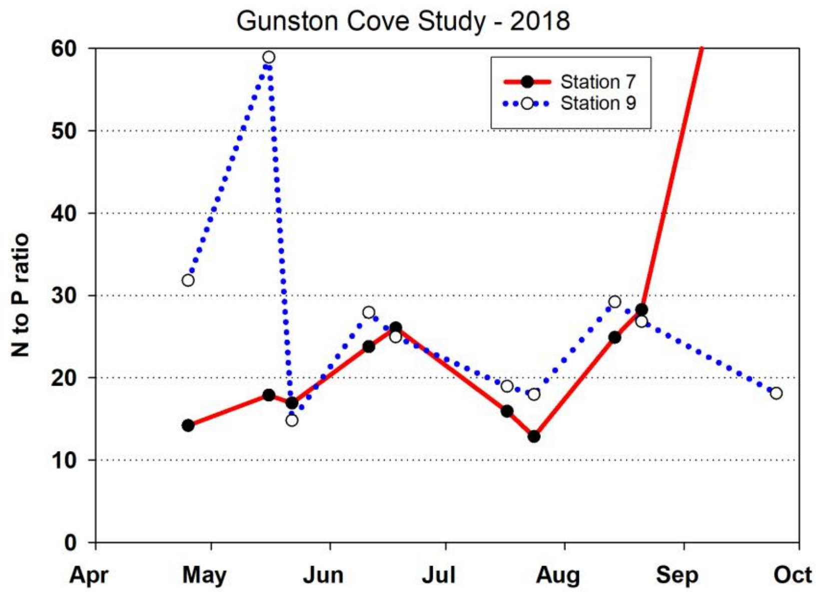
Figure 26. Total Phosphorus (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection: 0.03 mg/L)

Total phosphorus was similar at both sites on almost all dates and showed limited seasonal variation (Figure 26). Soluble reactive phosphorus was consistently higher in the river (Figure 27). A marked drop was observed in late July at both sites.



Soluble reactive phosphorus (SRP) is a measure of phosphate ion (PO_4^{-3}). Phosphate ion is the form in which P is most available to primary producers such as algae and aquatic plants in freshwater. However, SRP is often inversely related to the activity of primary producers because they tend to take it up so rapidly. So, higher levels of SRP indicate either a local source of SRP to the waterbody or limitation by a factor other than P.

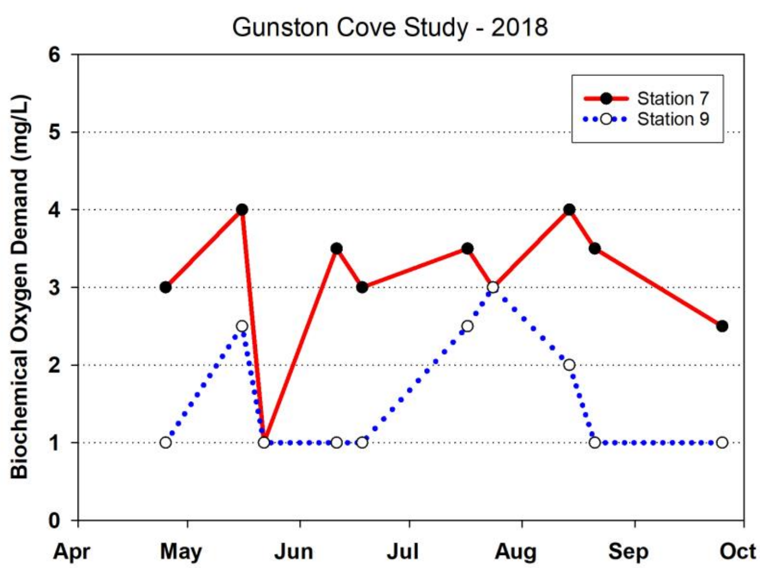
Figure 27. Soluble Reactive Phosphorus (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection = 0.005 mg/L)



N:P ratio is determined by summing all of the components of N (ammonia, nitrate, nitrite, and organic nitrogen) and dividing by total P. This ratio gives an indication of whether N or P is more likely to be limiting primary production in a given freshwater system. Generally, values above 7.2 are considered indicative of P limitation while values below 7.2 suggest N limitation. N limitation could lead to dominance by cyanobacteria who can fix their own N from the atmosphere.

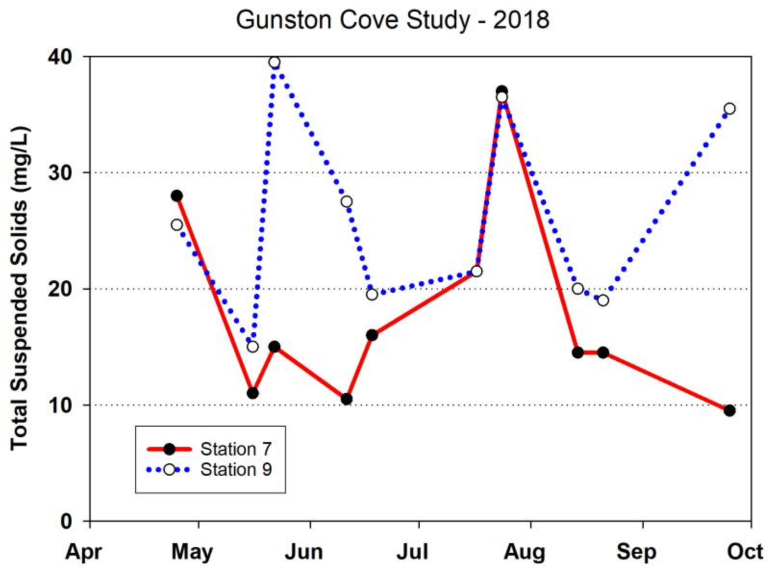
Figure 28. N/P Ratio (by mass). Fairfax County Lab Data. Month tick is at first day of month.

N/P ratio exhibited little consistent seasonal pattern at either site (Figure 28). Values bottomed out at about 13 in late July in the cove approaching N. Values in the river remained consistently above 15 throughout the year. Biochemical oxygen demand (BOD) was consistently higher in the cove than in the river (Figure 29). Many values in the river were below detection limits.



Biochemical oxygen demand (BOD) measures the amount of decomposable organic matter in the water as a function of how much oxygen it consumes as it breaks down over a given numittlber of days. Most commonly the number of days used is 5. BOD is a good indicator of the potential for oxygen depletion in water. BOD is composed both dissolved organic compounds in the water as well as microbes such as bacteria and algae which will respire and consume oxygen during the period

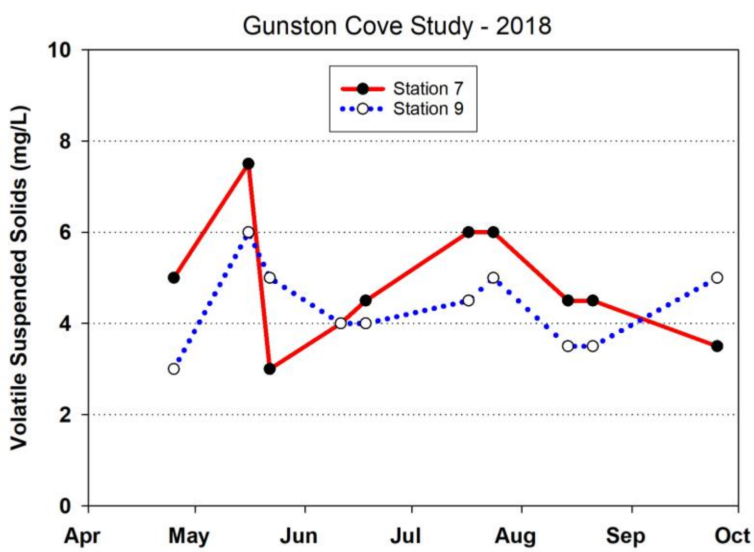
Figure 29. Biochemical Oxygen Demand (mg/L). Fairfax County Lab Data. Month tick is at first day of month.



Total suspended solids (TSS) is measured by filtering a known amount of water through a fine filter which retains all or virtually all particles in the water. This filter is then dried and the weight of particles on the filter determined by difference. TSS consists of both organic and inorganic particles. During periods of low river and tributary inflow, organic particles such as algae may dominate. During storm flow periods or heavy winds causing resuspension, inorganic particles may dominate.

Figure 30. Total Suspended Solids (mg/L). Fairfax County Lab Data. Month tick is at first day of month.

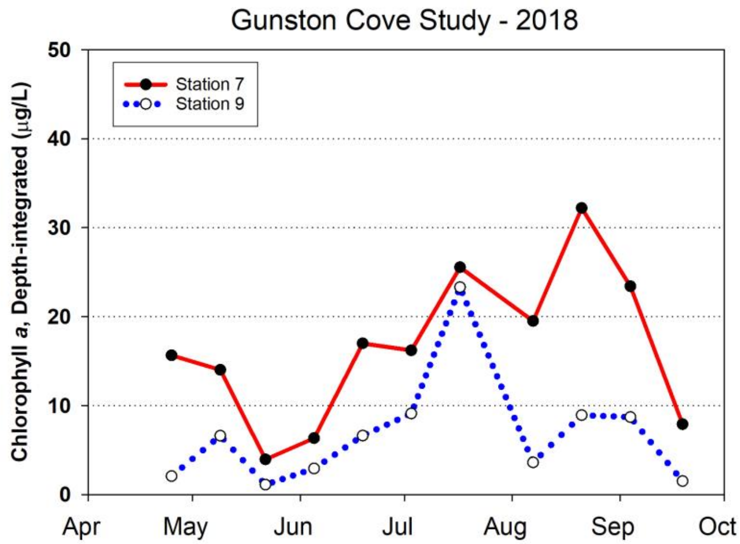
Total suspended solids was often quite elevated at both stations in 2018 (Figure 30). The peaks in late late July followed periods of very high runoff into the river. Volatile suspended solids was less clearly related to runoff events (Figure 31).



Volatile suspended solids (VSS) is determined by taking the filters used for TSS and then ashing them to combust (volatilize) the organic matter. The organic component is then determined by difference. VSS is a measure of organic solids in a water sample. These organic solids could be bacteria, algae, or detritus. Origins include sewage effluent, algae growth in the water column, or detritus produced within the waterbody or from tributaries. In summer in Gunston Cove a chief source is algal (phytoplankton) growth.

Figure 31. Volatile Suspended Solids (mg/L). Fairfax County Lab Data. Month tick is at first day of month.

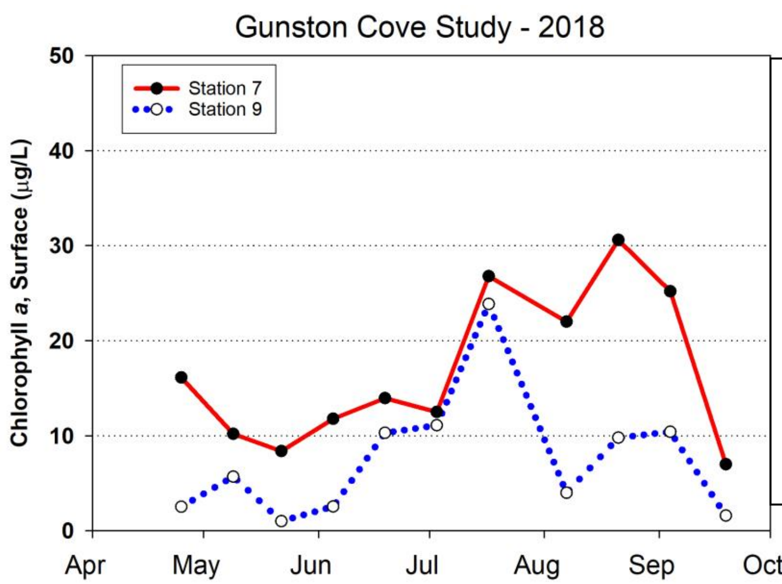
C. Phytoplankton -2018



Chlorophyll *a* is a measure of the amount of algae growing in the water column. These suspended algae are called phytoplankton, meaning "plant wanderers". In addition to the true algae (greens, diatoms, cryptophytes, etc.) the term phytoplankton includes cyanobacteria (sometimes known as "blue-green" algae). Both depth-integrated and surface chlorophyll values are measured due to the capacity of phytoplankton to aggregate near the surface under certain conditions.

Figure 32. Chlorophyll *a* (µg/L). Depth-integrated. GMU Lab Data. Month tick is at the first day of month.

Chlorophyll *a* at both stations displayed a distinct seasonal pattern in 2018 (Figure 32). Relatively high values in April and early May were decreased substantially in late May and early June due to flushing and poor light from storm runoff. In late June through August a general increase was observed in the cove despite numerous rainfall events. In the river the increase stopped abruptly in August. Depth-integrated and surface chlorophyll showed similar spatial and temporal patterns (Figure 33).



In the Gunston Cove, there is very little difference in surface and depth-integrated chlorophyll levels because tidal action keeps the water well-mixed which overcomes any potential surface aggregation by the phytoplankton. Summer chlorophyll concentrations above 30 ug/L are generally considered characteristic or eutrophic conditions.

Figure 33. Chlorophyll *a* (µg/L). Surface. GMU Lab Data. Month tick is at first day of month.

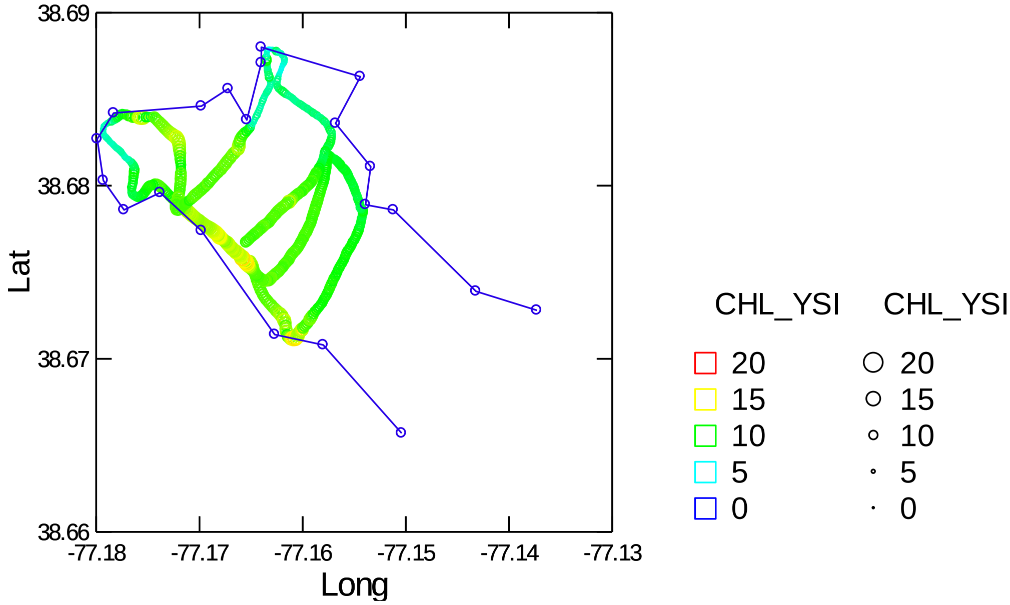


Figure 34. Chlorophyll *a* (µg/L) observed in transects across Gunston Cove during data mapping cruise on August 14, 2018.

Chlorophyll data from the datamapping cruise showed a pattern similar to that in DO and pH with higher values along the south shore of Gunston Cove (Figure 34). There was a very high correlation between chlorophyll and DO indicating that phytoplankton were very actively photosynthesizing and driving the pH above saturation with air (Figure 35).

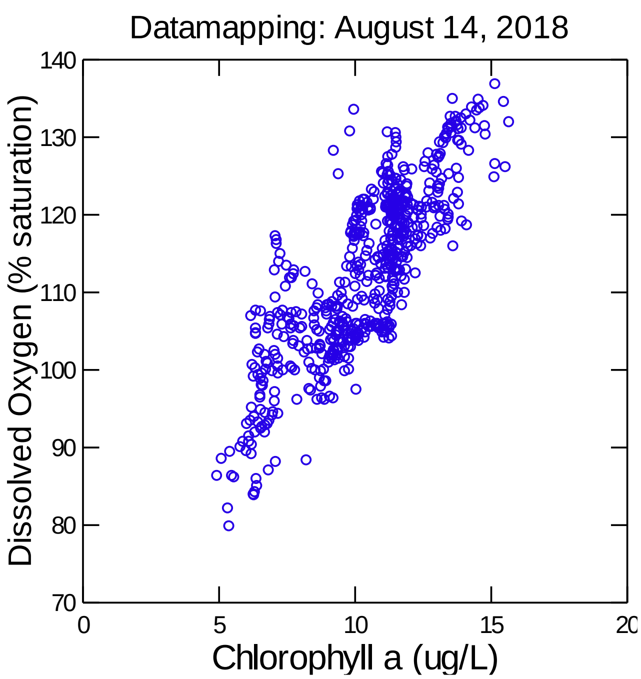
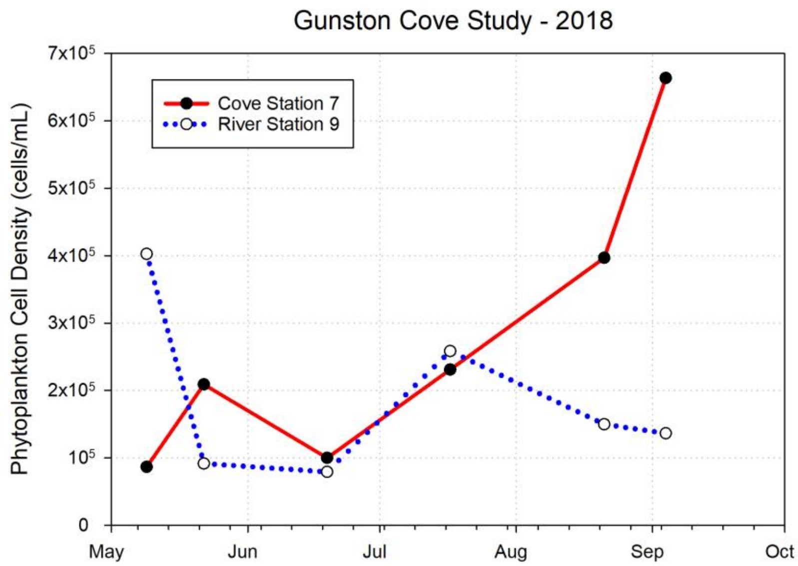


Figure 35. Scatterplot showing the strong correlation between Chlorophyll a and Dissolved Oxygen in Gunston Cove as derived from the datamapping cruise. (r=0.825, n=612)



Phytoplankton cell density provides a measure of the number of algal cells per unit volume. This is a rough measure of the abundance of phytoplankton, but does not discriminate between large and small cells. Therefore, a large number of small cells may actually represent less biomass (weight of living tissue) than a smaller number of large cells. However, small cells are typically more active than larger ones so cell density is probably a better indicator of activity than of biomass. The smaller cells are mostly cyanobacteria.

Figure 36. Phytoplankton Density (cells/mL).

In the cove phytoplankton density increased through most of the year reaching a peak in September (Figure 36). In the river the maximum was in spring. Total biovolume at both stations showed a distinct seasonal pattern peaking in July (Figure 37).

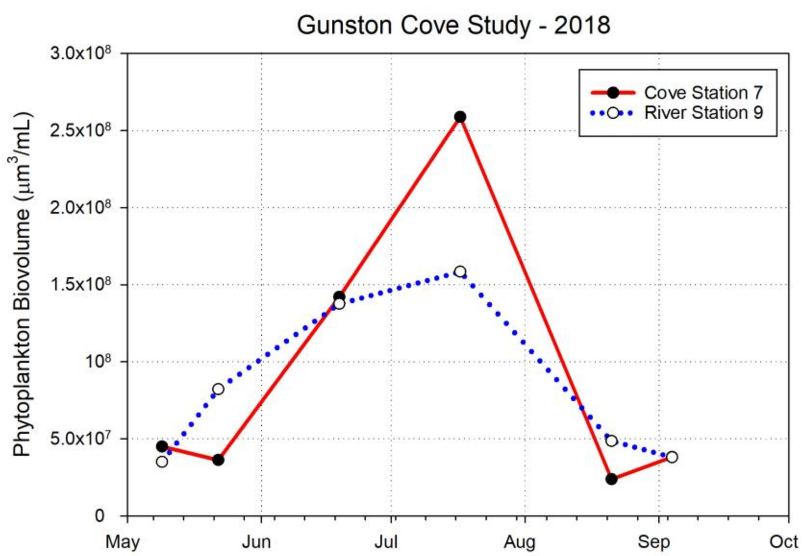
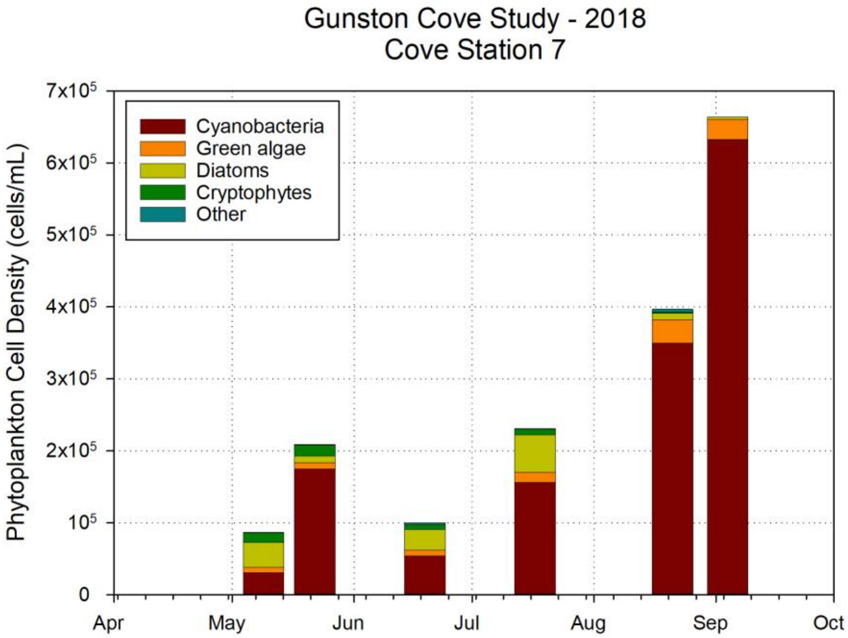


Figure 37. Phytoplankton Biovolume (um^3/mL).

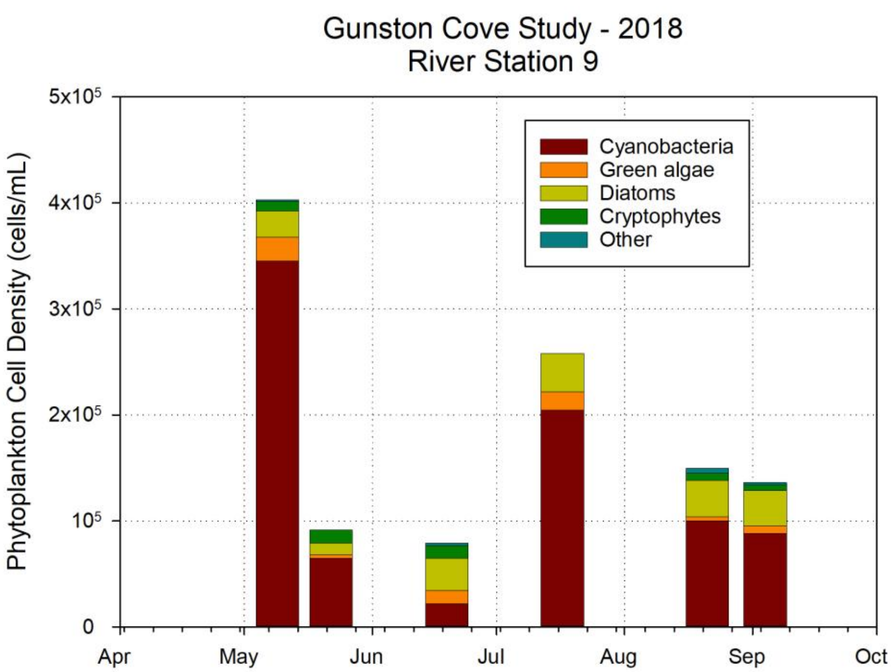
The volume of individual cells of each species is determined by approximating the cells of each species to an appropriate geometric shape (e.g. sphere, cylinder, cone, etc.) and then making the measurements of the appropriate dimensions under the microscope. Total phytoplankton biovolume (shown here) is determined by multiplying the cell density of each species by the biovolume of each cell of that species. Biovolume accounts for the differing size of various phytoplankton cells and is probably a better measure of biomass. However, it does not account for the varying amount of water and other nonliving constituents in cells.



Total phytoplankton cell density can be broken down by major group. The top four groups represent those which are generally most abundant. **Other** includes euglenoids and dinoflagellates. Due to their small size cyanobacteria typically dominate cell density numbers. Their numbers are typically highest in the late summer reflecting an accumulation of cells during favorable summer growing conditions.

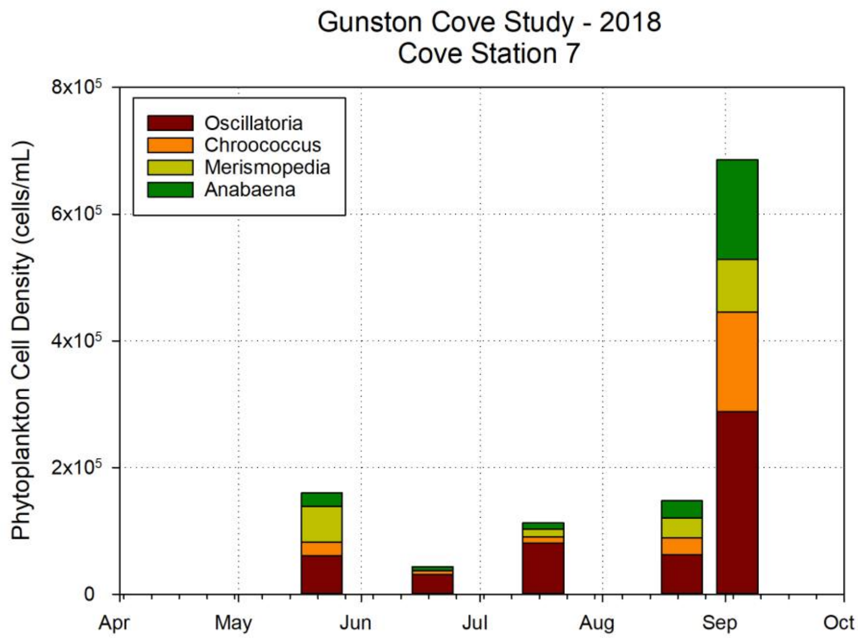
Figure 38. Phytoplankton Density by Major Group (cells/mL). Gunston Cove.

In 2018 phytoplankton density in the cove was dominated by cyanobacteria on all dates (Figure 38). Diatoms were found in significant numbers in May, June, and July with green algae important in August and September. In the river cyanobacteria were again the most numerous for virtually the entire year (Figure 39). Diatoms were more abundant in June.



In the river cyanobacteria normally follow similar patterns as in the cove, but attaining lower abundances. This is probably due to the deeper water column which leads to lower effective light levels and greater mixing. Other groups such as diatoms and green algae tend to be more important on a relative basis than in the cove.

Figure 39. Phytoplankton Density by Major Group (cells/mL). River.

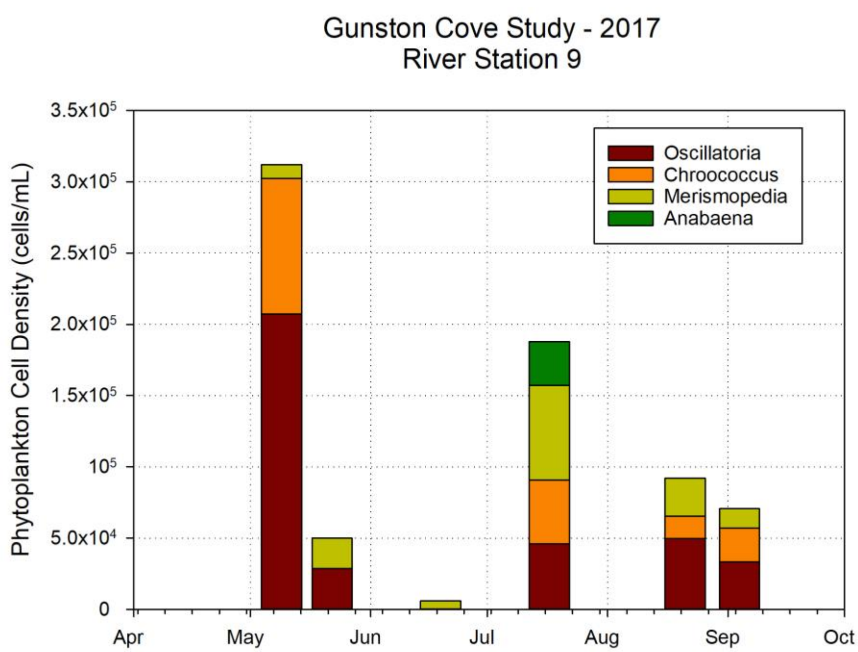


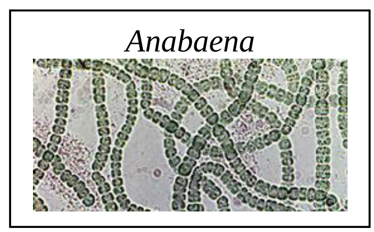
The dominant cyanobacteria on a numerical basis were:

- *Anabaena* – a filament with bead-like cells & heterocysts
- *Microcystis* – an irregular colony of spherical cells
- *Oscillatoria* – a filament with cylindrical cells
- *Merismopedia* -- a flat plate of cells in a rectangular arrangement
- *Chroococcus* – individual spherical cells
- *Raphidiopsis* – a filament of cylindrical cells

Figure 40. Phytoplankton Density by Dominant Cyanobacteria (cells/mL). Gunston Cove.

Oscillatoria was the most abundant cyanobacterium in the cove on most dates (Figure 40). In September, *Anabaena* and *Chroococcus* were also very important. In the river *Oscillatoria* was generally dominant with a strong showing from *Chroococcus* in early May and *Merismopedia* in July (Figure 41).





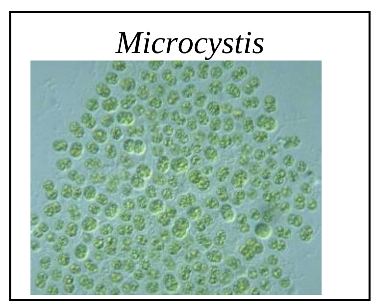
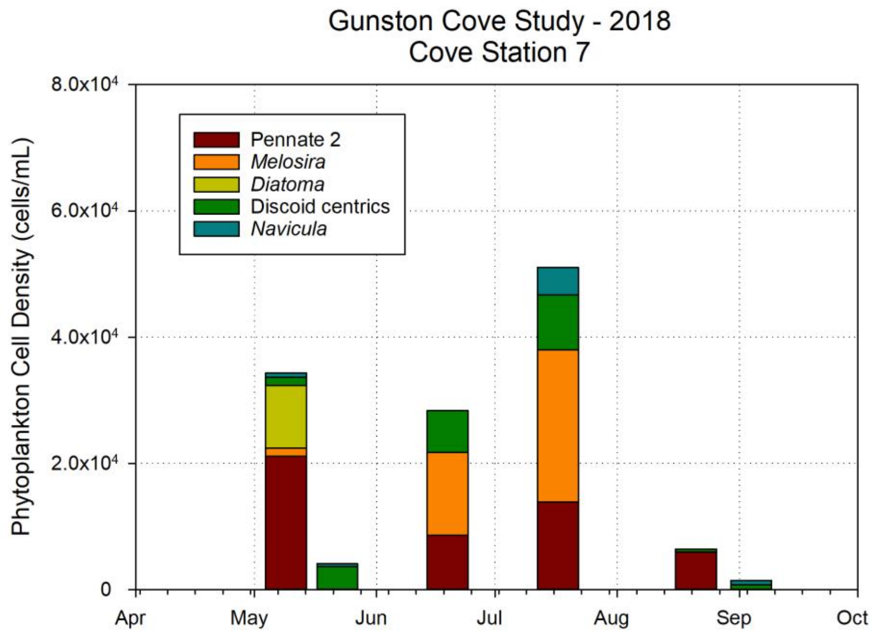


Figure 41. Phytoplankton Density by Dominant Cyanobacteria (cells/mL). River.

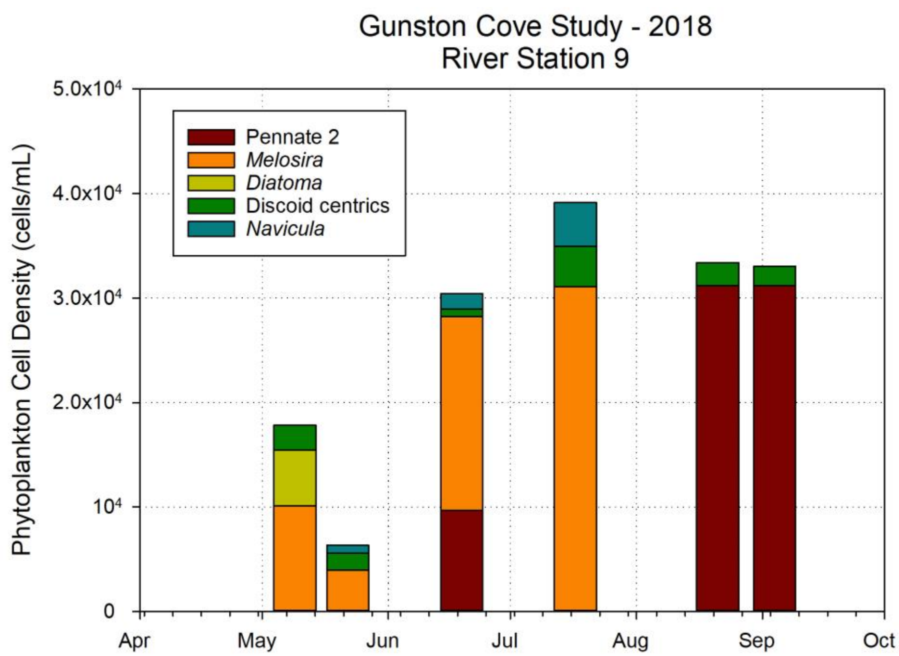


The most numerous diatoms in the phytoplankton were:

- *Melosira* – a filamentous centric diatom
- Centrics – discoid centric diatoms
- Pennate 2 – a small pinnate diatom
- Pennate 1 – a small pinnate diatom
- *Asterionella* – a small pennate diatom that forms spoked - wheel colony

Figure 42. Phytoplankton Density by Dominant Diatoms (cells/mL). Gunston Cove.

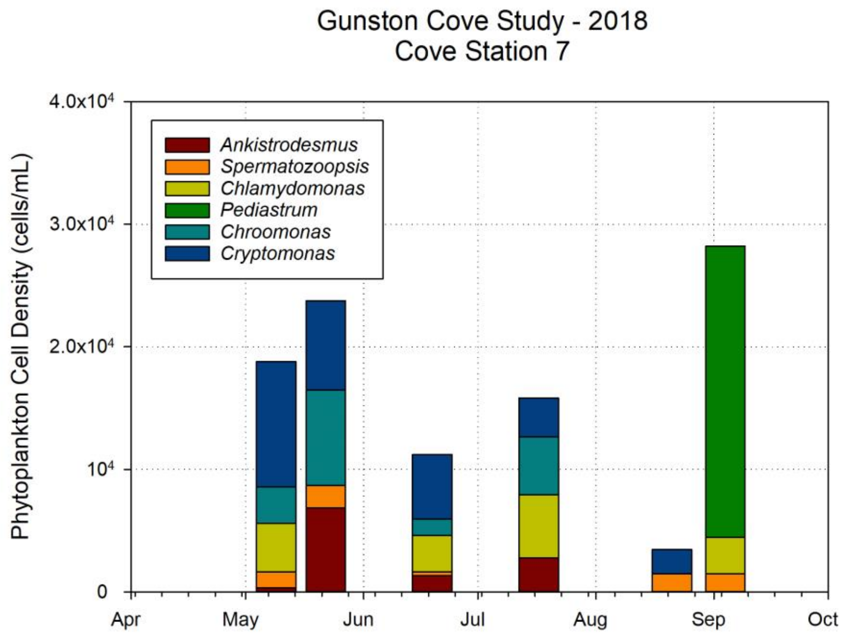
Diatom cell density was dominated by *Melosira* or Pennate 2 in most samples from the cove station (Figure 42). Discoid centrics were also important. In the river *Melosira* was dominant in spring and summer with Pennate 2 being most abundant in fall (Figure 43).



Melosira

Discoid Centrics

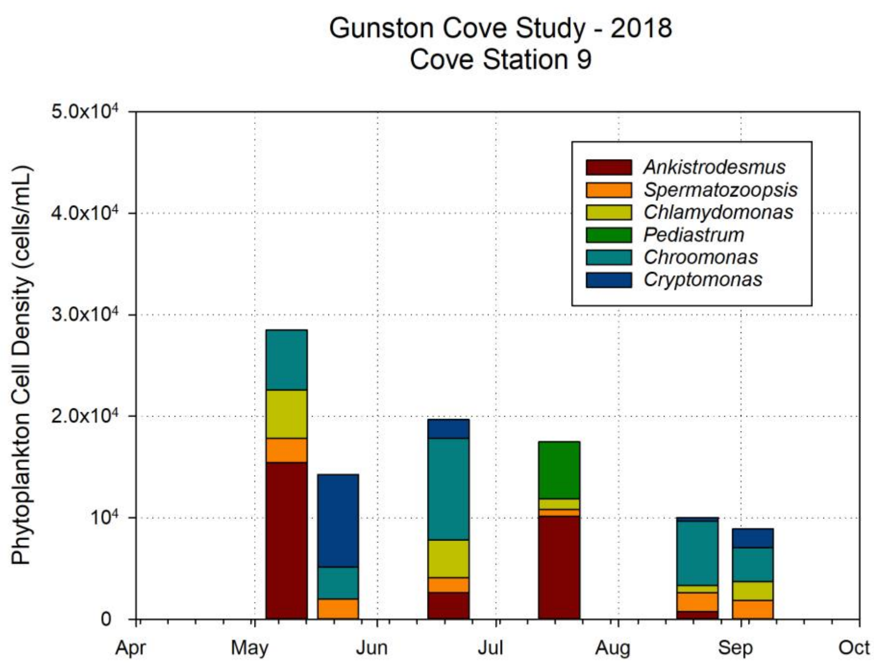
Figure 43. Phytoplankton Density by Dominant Diatoms (cells/mL). River.



The most numerous phytoplankton among the cryptophytes, green algae and others were:
- *Cryptomonas* – an ellipsoidal, flagellated unicell
- *Chroomonas* – a flagellated cryptomonad unicell
- *Dictyosphaerium* – colony of small green unicells
- *Selenastrum* – single green algal cell as curved rod
- *Pediastrum* – green algal colony
- *Botryococcus* – single green coccoid cell

Figure 44. Phytoplankton Density (#/mL) by Dominant Other Taxa. Gunston Cove.

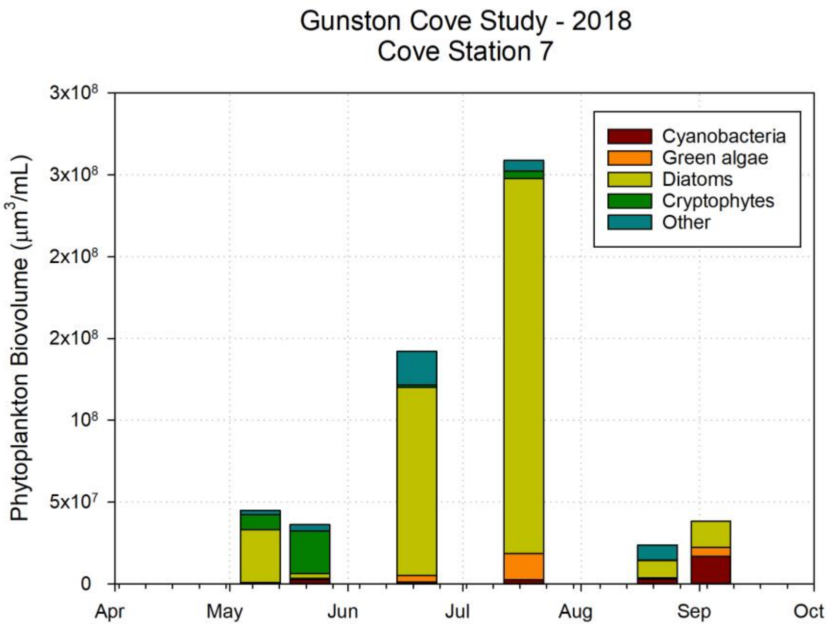
In the cove a number of other taxa were important, but on most dates *Cryptomonas*, *Chroomonas*, and *Chlamydomonas* were generally the most abundant (Figure 44). In the river these tthree were again abundant on all dates. *Ankistrodesmus* was also dominant on some dates (Figure 45).




Cryptomonas


Scenedesmus

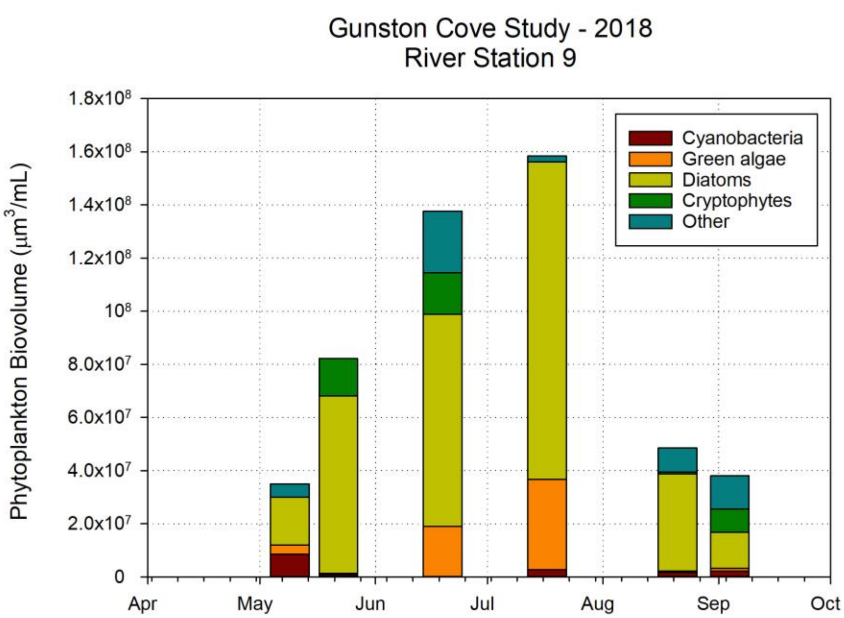
Figure 45. Phytoplankton Density (#/mL) by Dominant Other Taxa. River.



Total phytoplankton biovolume can be broken down into groups:
- **Cyanobacteria** ("blue-green" algae)
- **Green algae**
- **Diatoms** – includes both centric and pinnate
- **Cryptophytes**
- **Other** – includes euglenoids, chrysophytes, and dinoflagellates

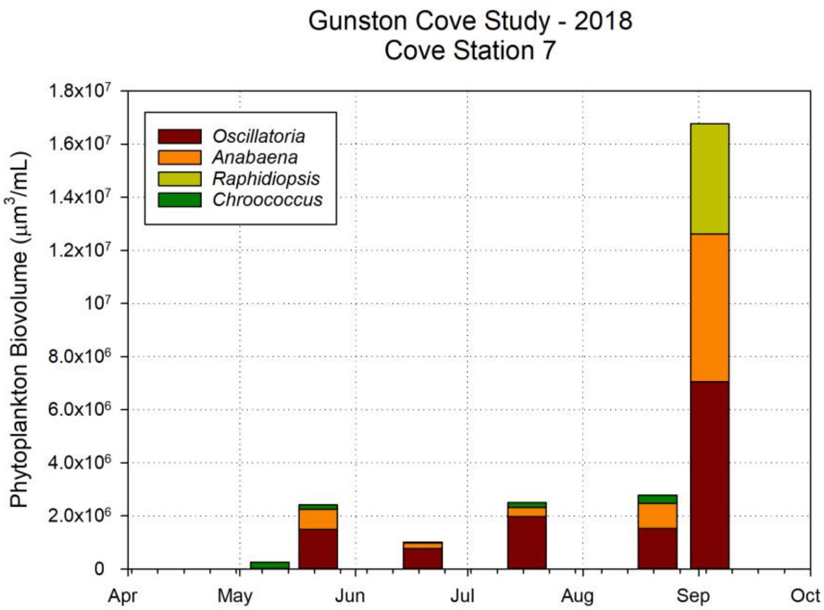
Figure 46. Phytoplankton Biovolume (um^3/mL) by Major Groups. Gunston Cove.

In the cove biovolume was strongly dominated by diatoms on most dates (Figure 46). Despite their greater cell density, cyanobacteria were much lower on almost all dates. Cryptophytes, green algae, and other algae were important on some dates. In the river, diatoms were again dominant in biovolume for most of the year (Figure 47).



While dominating cell density, cyanobacteria typically make up a much smaller portion of phytoplankton biovolume. As with cell density, biovolume is generally greater in the cove.

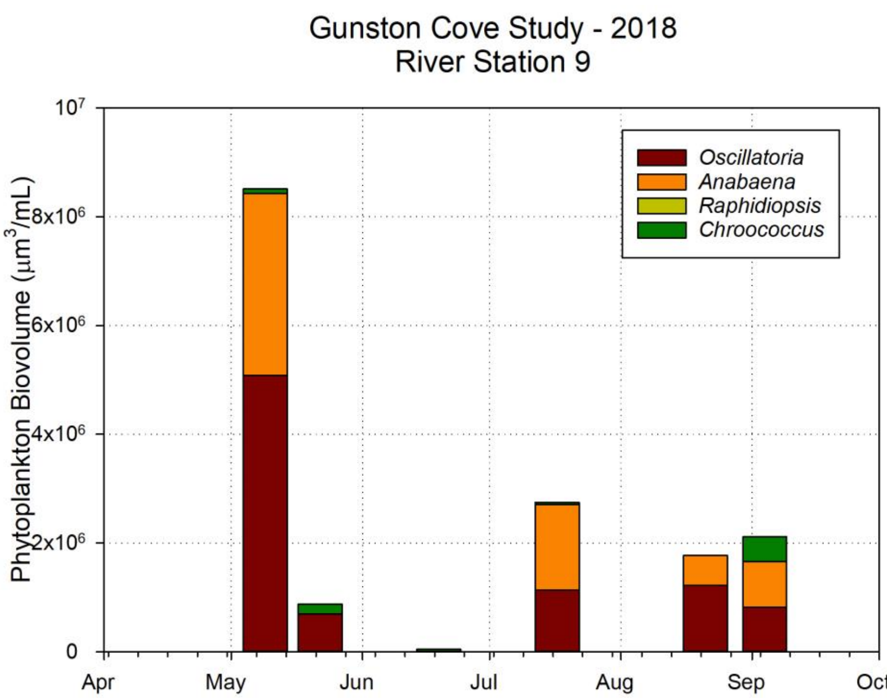
Figure 47. Phytoplankton Biovolume (um^3/mL) by Major Groups. River.



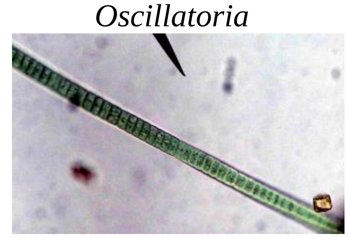
The dominant cyanobacteria on a biovolume basis were:
- *Anabaena* – a filament with bead-like cells & heterocysts
- *Rhabdoderma* – rod-shaped cells in small packets
- *Oscillatoria* – a filament with cylindrical cells
- *Chroococcus* – individual spherical cells
- *Raphidiopsis* – a filament of cylindrical cells

Figure 48. Phytoplankton Biovolume (um^3/mL) by Cyanobacteria Taxa. Gunston Cove.

Oscillatoria accounted for most of the cyanobacterial biovolume in the cove except for the September sample in which *Anabaena* and *Raphidiosis* were important (Figure 48). *Anabaena* was also important in many samples in summer. In the river cyanobacteria were somewhat less abundant on most dates, but *Oscillatoria* and *Anabaena* were again the dominants (Figure 49).



Oscillatoria



Chroococcus

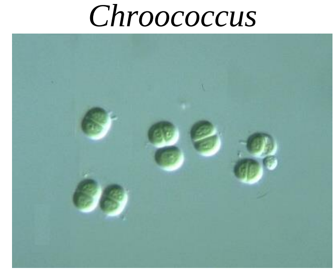
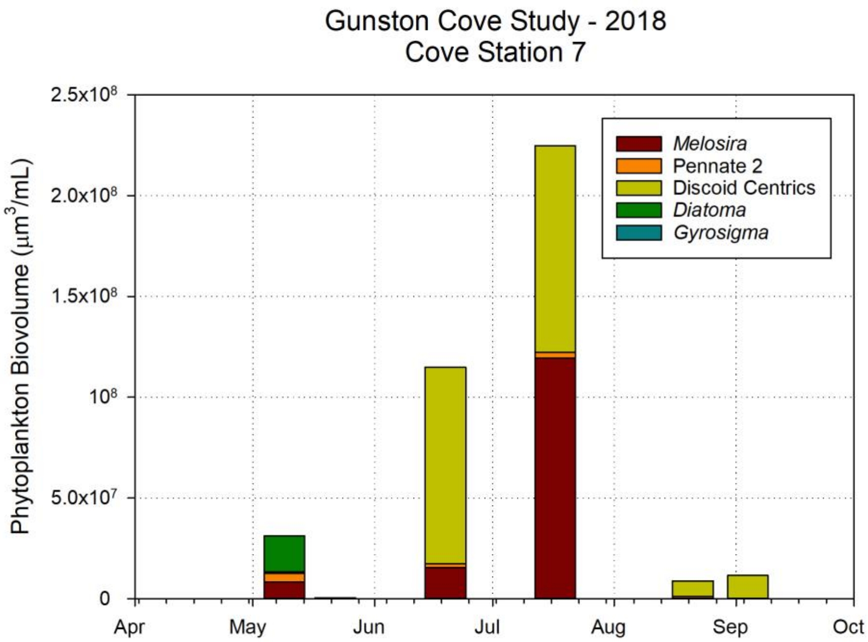


Figure 49. Phytoplankton Biovolume (um^3/mL) by Cyanobacterial Taxa. River.

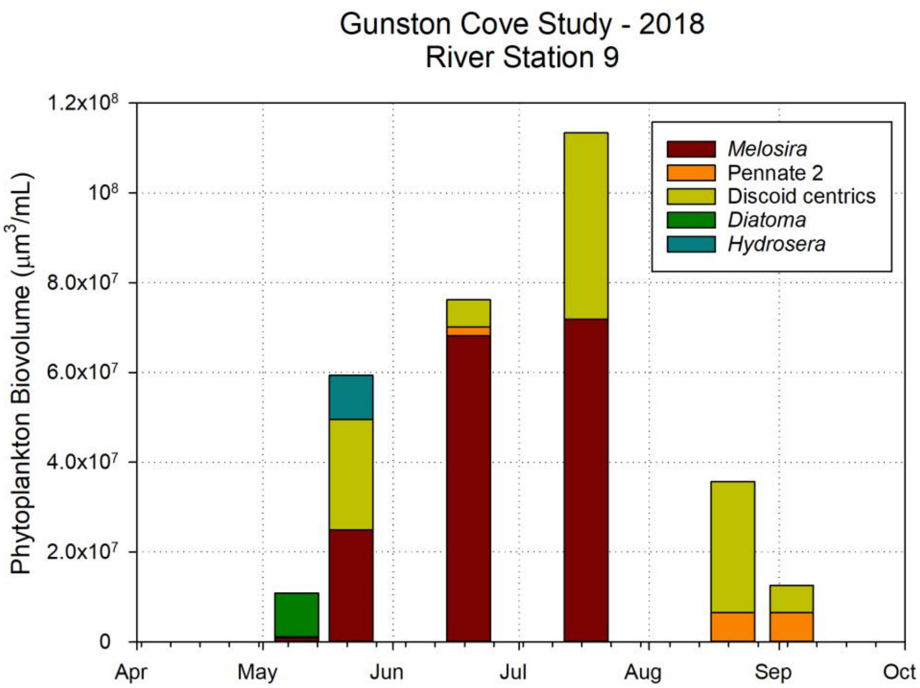


The most numerous diatoms in the phytoplankton were:

- *Melosira* – a filamentous centric diatom
- Centrics – discoid centric diatoms
- *Stauroneis* – larger pennate diatom
- Pennate 2 – a small pinnate diatom
- Pennate 1 – a small pinnate diatom
- *Surirella* – a larger pennate diatom
- *Nitzschia* – a small pennate diatom

Figure 50. Phytoplankton Biovolume (um^3/mL) by Diatom Taxa. Gunston Cove.

In the cove *Melosira* and discoid centrics were responsible for the large increase in June and July and were dominant on all dates except in May when *Diatoma* had slightly more biovolume (Figure 50). In the river *Melosira* was most important in late May, June and July with discoid centrics being important almost all year (Figure 51).



Melosira

Surirella

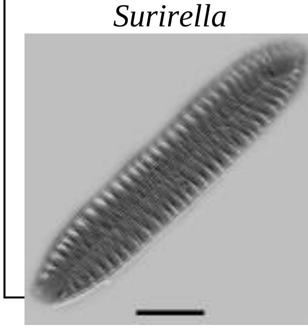
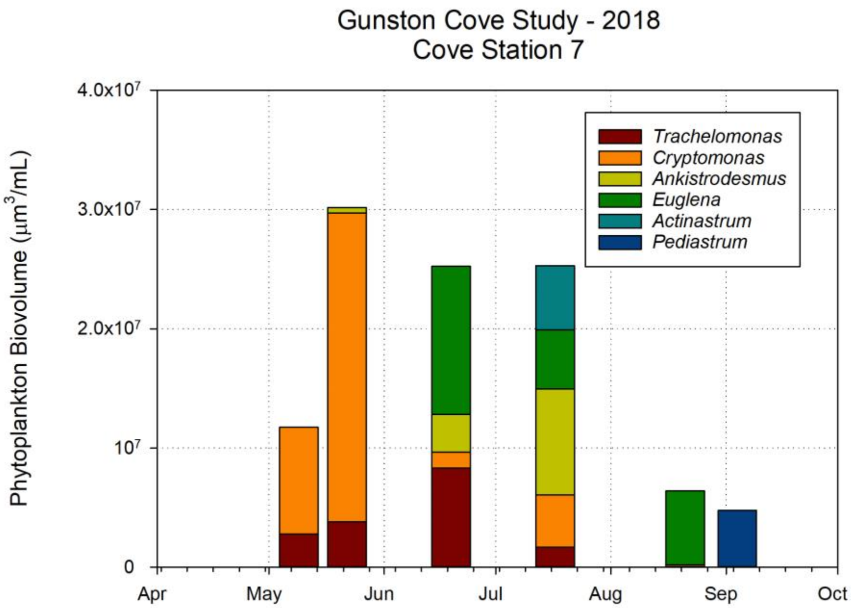


Figure 51. Phytoplankton Biovolume (um^3/mL) by Diatom Taxa. River.



The most numerous phyto-plankton among the cryptophytes, green algae and others were:

Euglena – large euglenoid flagellate

Cryptomonas – an ellipsoidal, flagellated unicell

Carteria – flagellated green unicell

Mallomonas – unicellular scaled flagellate

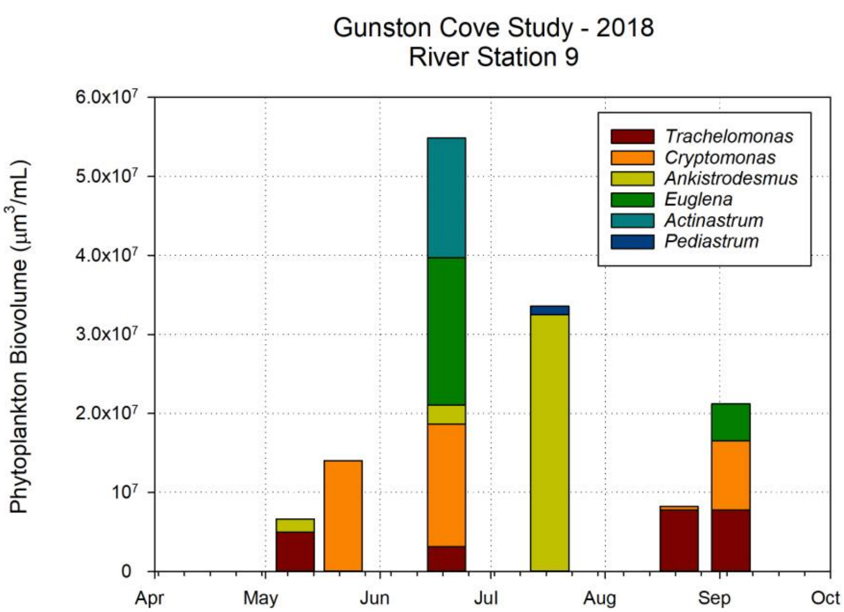
Trachelomonas – spherical, armored euglenoid

Ankistrodesmus – rod-like single celled green alga

Oocystis –green unicells in small packets

Figure 52. Phytoplankton Biovolume (um^3/mL) by Dominant Other Taxa. Gunston Cove.

A number of other taxa were present in the cove in 2018 and *Euglena*, *Cryptomonas*, and *Ankistrodesmus* and *Trachelomonas* made strong contributions to biovolume on most dates (Figure 52). In the river the same four taxa were predominant as was *Actinastrum* on one date (Figure 53).

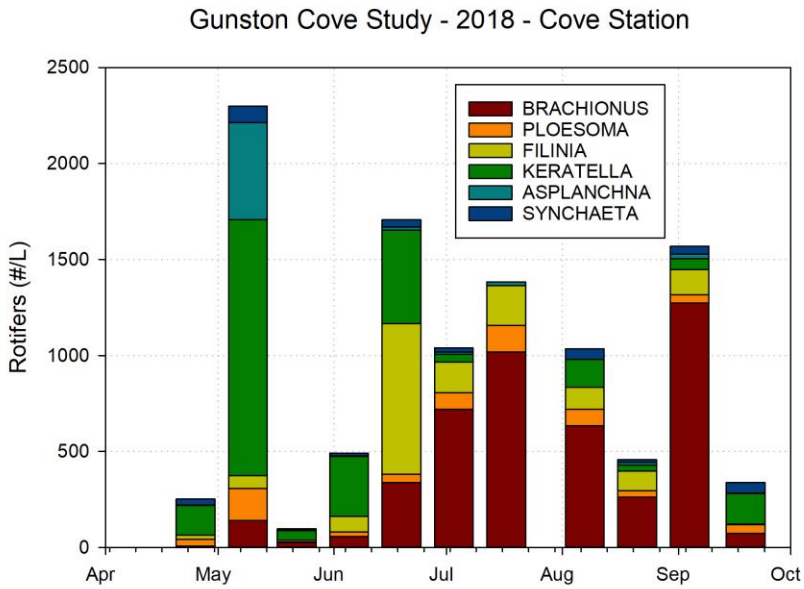


Cryptomonas

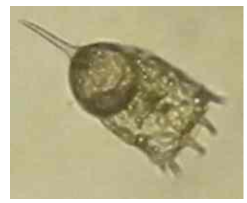
Euglena

Figure 53. Phytoplankton Biovolume (um^3/mL) by Dominant Other Taxa. River.

D. Zooplankton – 2018



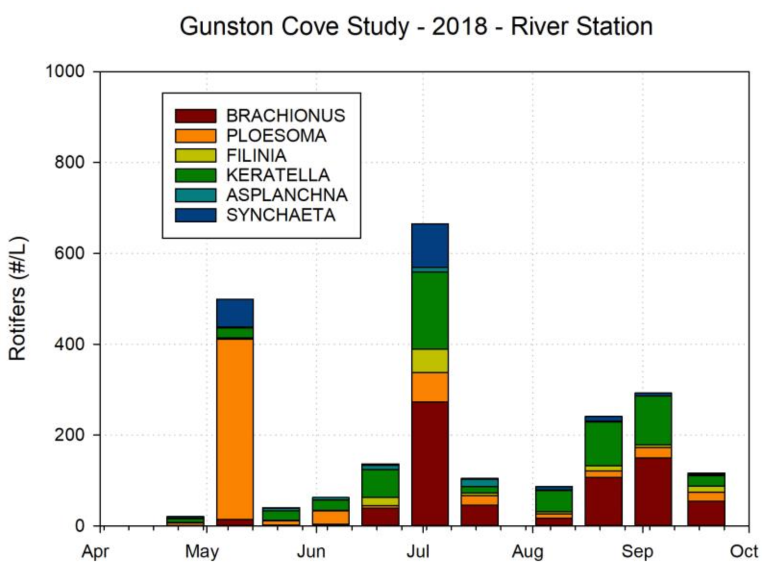
Brachionus (Sta 7, RCJ)



Keratella (Sta 7, RCJ)

Figure 54. Rotifer Density by Dominant Taxa (#/L). Cove.

In the cove, rotifers exhibited a very strong presence in early May led by *Keratella* and then declined strongly in late May, and then increased again in June to an early summer peak (Figure 54). A general decline was observed through the summer followed by another peak in early September. *Brachionus* and *Keratella* were most prominent for most of the year in the cove. In the river rotifers were consistently less abundant than in the cove, but did have an early May peak followed by a multiweek period of low densities and a second peak in late June with lower values thereafter (Figure 55). *Ploesoma* was dominant in early May with *Keratella* and *Brachionus* dominant on other dates.



Brachionus (c. 50 um)

Conochilidae

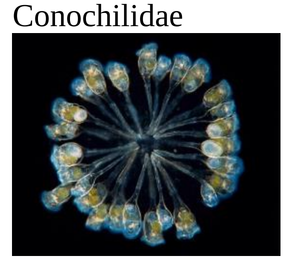


Figure 55. Rotifer Density by Dominant Taxa (#/L). River.

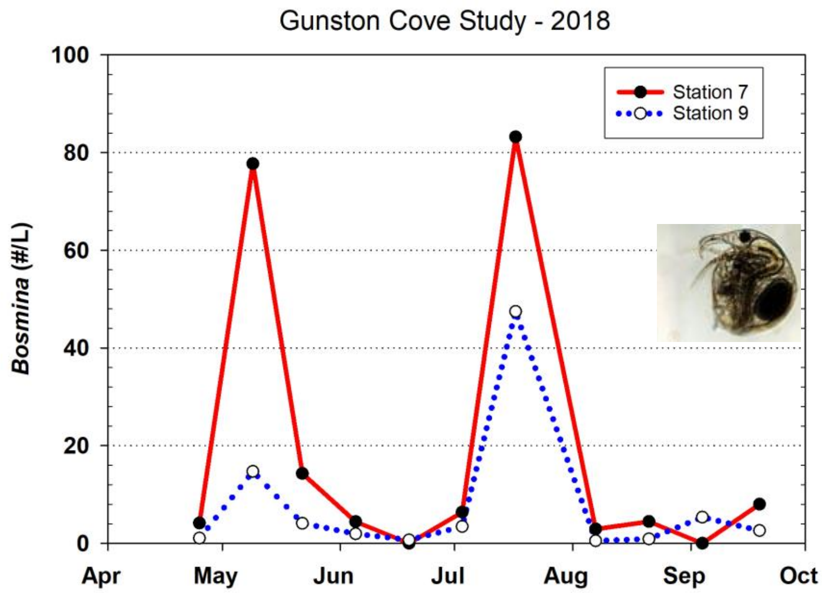


Figure 56. *Bosmina* Density by Station (#/L).

Bosmina is a small-bodied cladoceran, or "waterflea", which is common in lakes and freshwater tidal areas. It is typically the most abundant cladoceran with maximum numbers generally about 100-1000 animals per liter. Due to its small size and relatively high abundances, it is enumerated in the micro-zooplankton samples. *Bosmina* can graze on smaller phytoplankton cells, but can also utilize some cells from colonies by knocking them loose.

In 2018 the small cladoceran *Bosmina* was abundant on only two dates in both areas, early May and mid July (Figure 56). *Diaphanosoma,* typically the most abundant larger cladoceran in the study area, was scarce in 2018, but reached a substantial maximum of over 1000 per m^3 in mid-July in the cove (Figure 57).

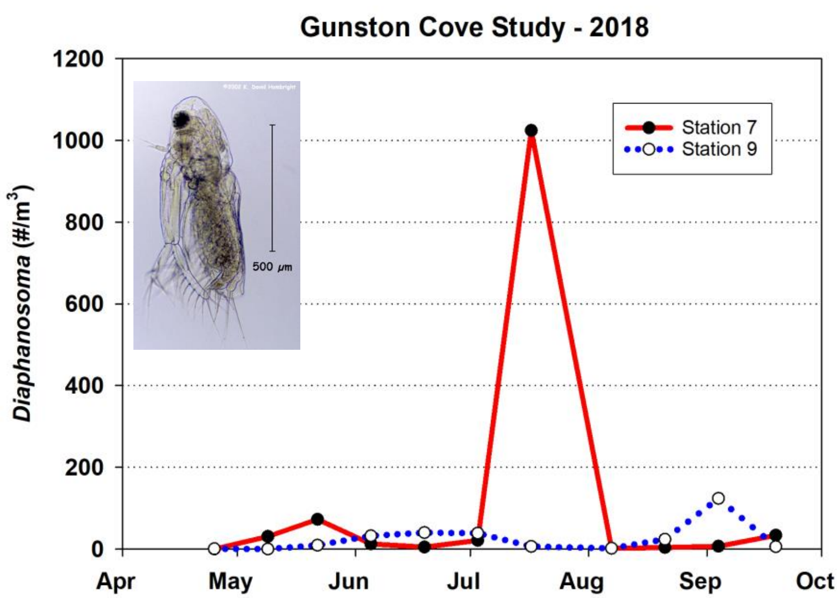
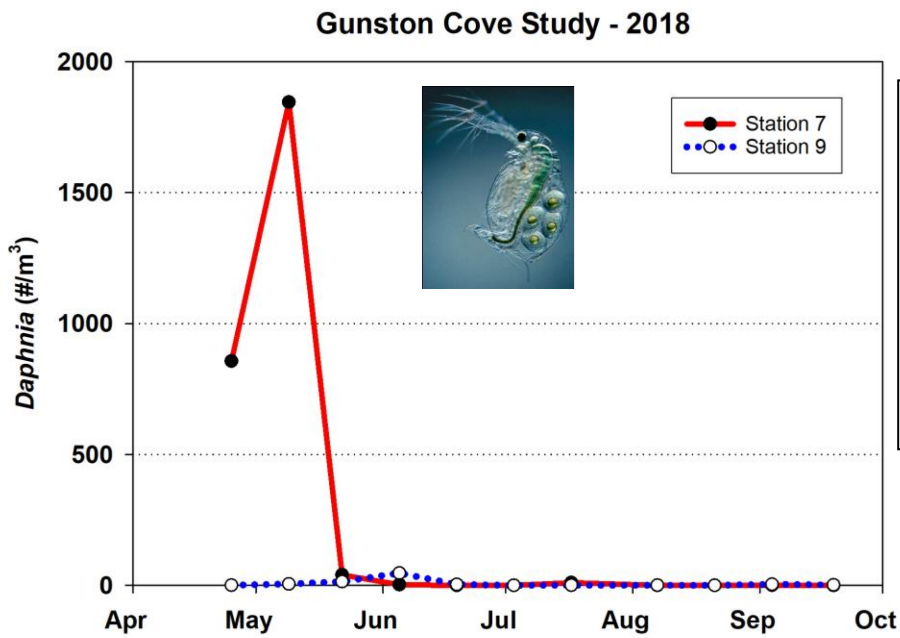


Figure 57. *Diaphanosoma* Density by Station (#/m^3).

Diaphanosoma is the most abundant larger cladoceran found in the tidal Potomac River. It generally reaches numbers of 1,000-10,000 per m^3 (which would be 1-10 per liter). Due to their larger size and lower abundances, *Diaphanosoma* and the other cladocera are enumerated in the macrozooplankton samples. *Diaphanosoma* prefers warmer temperatures than some cladocera and is often common in the summer.



Daphnia, the common waterflea, is one of the most efficient grazers of phytoplankton in freshwater ecosystems. In the tidal Potomac River it is present, but has not generally been as abundant as *Diaphanosoma*. It is typically most common in spring.

Figure 58. *Daphnia* Density by Station (#/m^3).

In 2018 *Daphnia* exhibited very low values except in the cove in early May where a value of over 1800/m^3 was attained (Figure 58). *Ceriodaphnia* was generally quite low except in late April and early May (Figure 59).

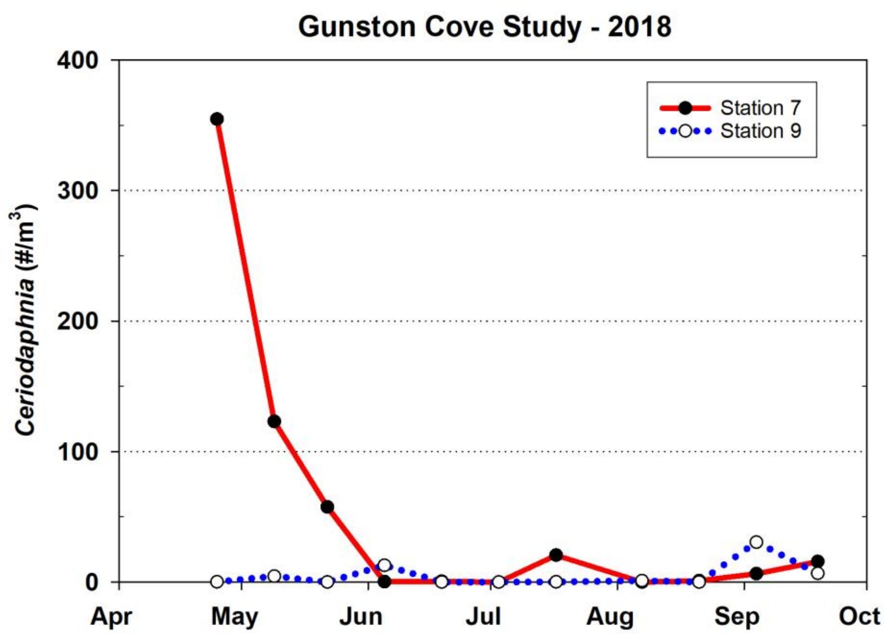
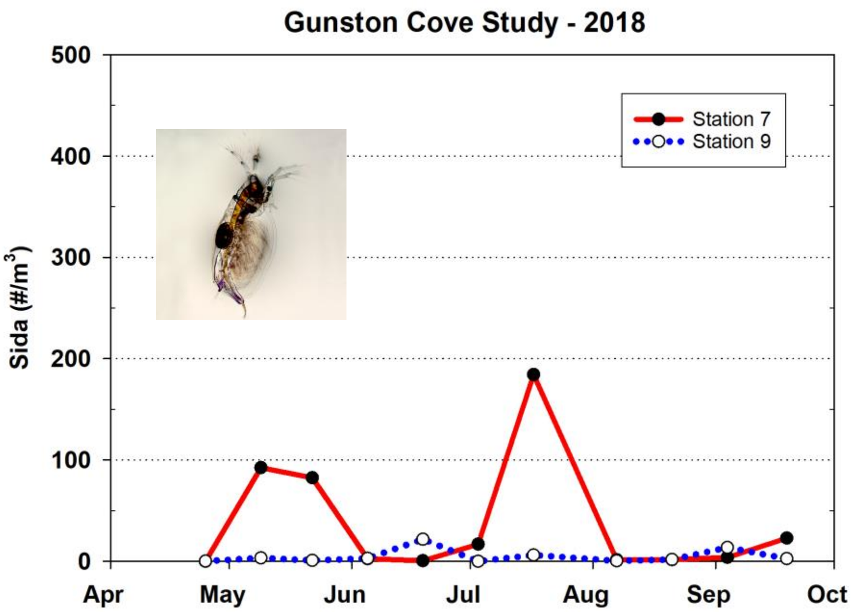


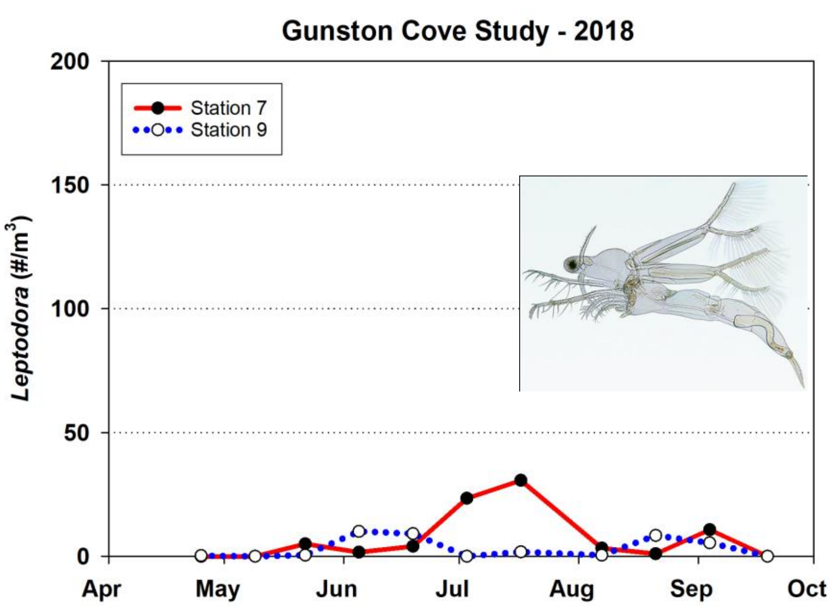
Figure 59. *Ceriodaphnia* Density by Station (#/m^3).



Sida is another waterflea that is often observed in the tidal Potomac River. Like the other cladocera mentioned so far, *Sida* grazes on phytoplankton to obtain its food supply.

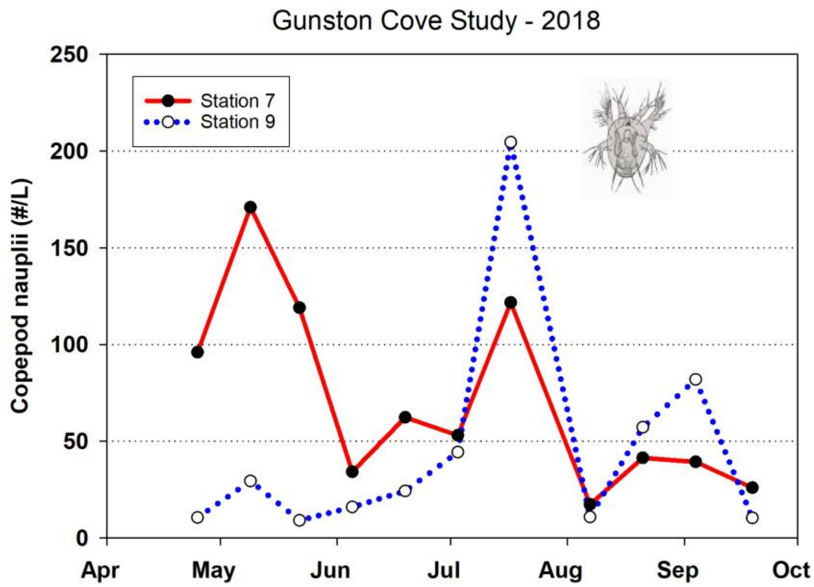
Figure 60. *Sida* Density by Station (#/m^3).

Sida, a smallish cladoceran related to *Diaphanosoma*, showed some subdued and short-lived peaks in the cove at times similar to the other cladocerans (Figure 60). *Leptodora*, the large cladoceran predator, was not very abundant in 2018 at either station (Figure 61). Peak values of about 30/m^3 in mid July were observed in the cove.



Leptodora is substantially larger than the other cladocera mentioned. Also different is its mode of feeding – it is a predator on other zooplankton. It normally occurs for brief periods in the late spring or early summer.

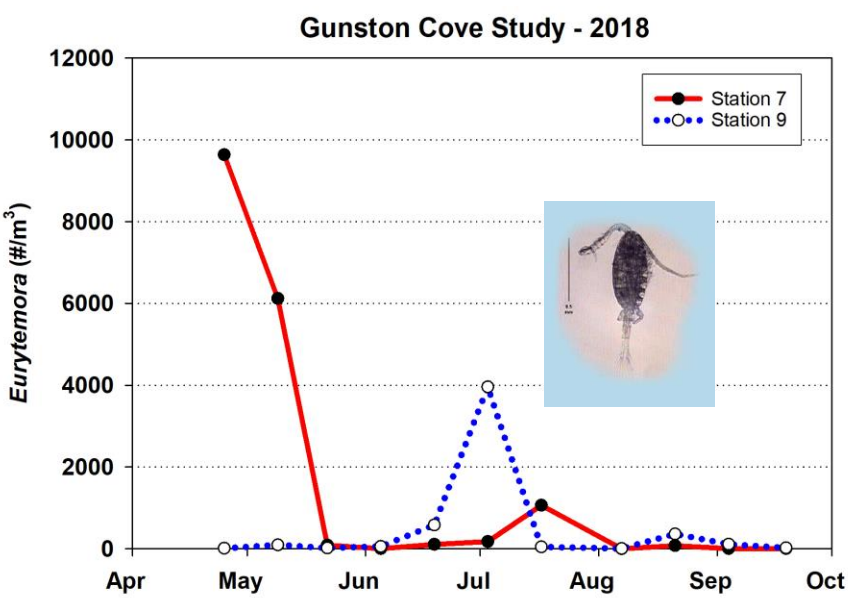
Figure 61. *Leptodora* Density by Station (#/m^3).



Copepod eggs hatch to form an immature stage called a nauplius. The nauplius is a larval stage that does not closely resemble the adult and the nauplii of different species of copepods are not easily distinguished so they are lumped in this study. Copepods go through 5 naupliar molts before reaching the copepodid stage which is morphologically very similar to the adult. Because of their small size and high abundance, copepod nauplii are enumerated in the micro-zooplankton samples.

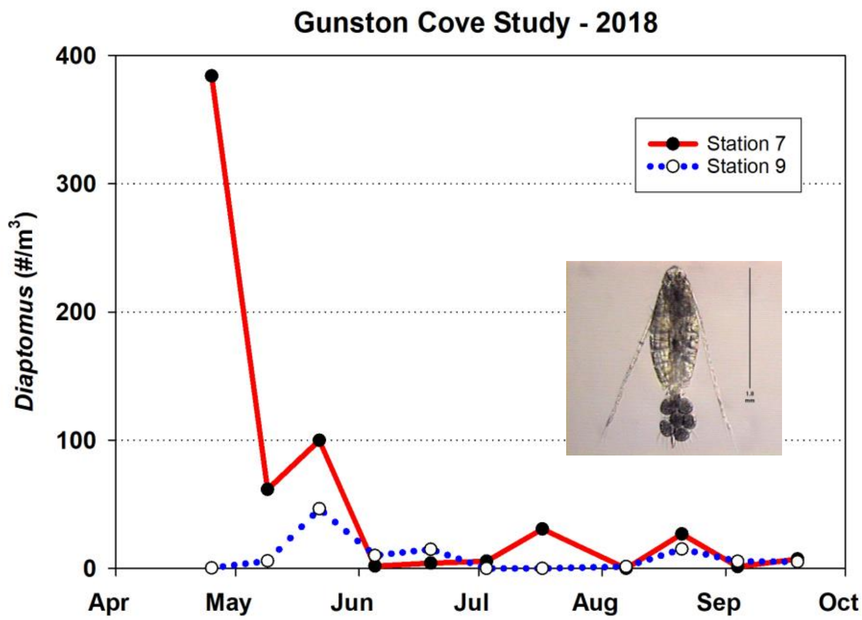
Figure 62. Copepod Nauplii Density by Station (#/L).

In the cove copepod nauplii peaked in early May and again in mid-July at moderate levels (Figure 62). In the river there was a very limited increase in late May, but a strong increase in mid July. *Eurytemora* attained high densities of nearly 12,000/m^3 in April in the cove, but decreased strongly during May remained low for the rest of the year (Figure 63). In the river *Eurytemora* was generally lower, but attained 4000/m^3 in early July.



Eurytemora affinis is a large calanoid copepod characteristic of the freshwater and brackish areas of the Chesapeake Bay. *Eurytemora* is a cool water copepod which often reaches maximum abundance in the late winter or early spring. Included in this graph are adults and those copepodids that are recognizable as *Eurytemora*.

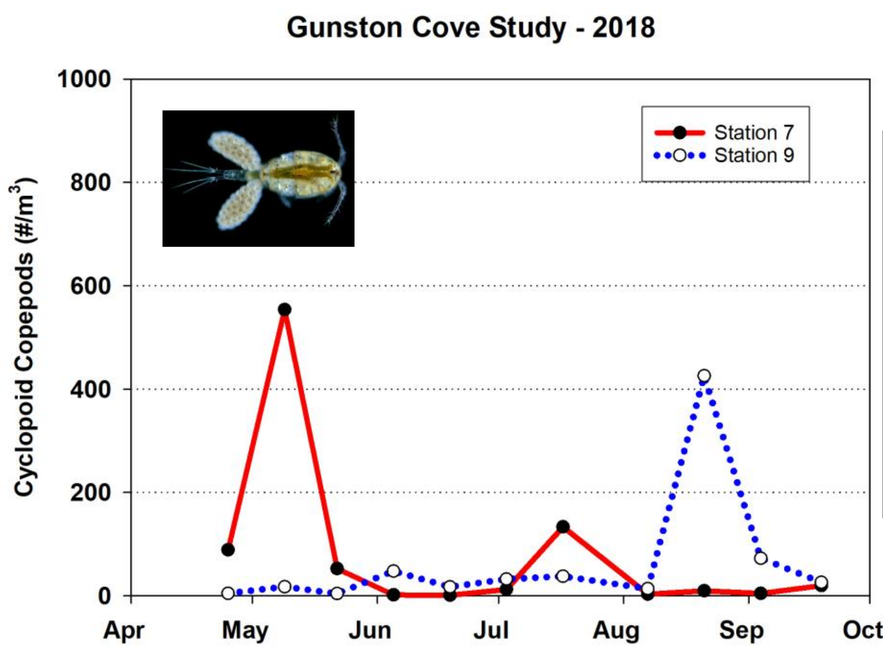
Figure 63. *Eurytemora* Density by Station (#/m^3).



Diaptomus pallidus is a calanoid copepod often found in moderate densities in the Gunston Cove area. *Diaptomus* is an efficient grazer of algae, bacteria, and detrital particles in freshwater ecosystems Included in this graph are adults and those copepodids that are recognizable as *Diaptomus*.

Figure 64. *Diaptomus* Density by Station (#/m^3).

Diaptomus was was restricted to low values for most of 2018 after starting relatively abundant in late April in the cove (Figure 64). Cyclopoid copepods showed a strong peak in the cove in early May, but then declined for the rest of the year. In the river the peak was found in mid August (Figure 65).



Cyclopoids are the other major group of planktonic copepods. Cyclopoids feed on individual particles suspended in the water including small zooplankton as well as phytoplankton. In this study we have lumped all copepodid and adult cyclopoids together.

Figure 65. Cyclopoid Copepods by Station (#/m^3).

E. Ichthyoplankton-2018

Larval fishes are transitional stages in the development of juvenile fishes. They range in development from newly hatched, embryonic fish to juvenile fish with morphological features similar to those of an adult. Many fishes such as clupeids (herring family), White Perch, Striped Bass, and Yellow Perch disperse their eggs and sperm into the open water. The larvae of these species are carried with the current and termed “ichthyoplankton”. Other fish species such as sunfishes and bass lay their eggs in “nests” on the bottom and their larvae are rare in the plankton.

After hatching from the egg, the larva draws nutrition from a yolk sack for a few days time. When the yolk sack diminishes to nothing, the fish begins a life of feeding on other organisms. This post yolk sack larva feeds on small planktonic organisms (mostly small zooplankton) for a period of several days. It continues to be a fragile, almost transparent, larva and suffers high mortality to predatory zooplankton and juvenile and adult fishes of many species, including its own. When it has fed enough, it changes into an opaque juvenile, with greatly enhanced swimming ability. It can no longer be caught with a slow-moving plankton net, but is soon susceptible to capture with the seine or trawl net.

In 2018, we collected 14 samples (7 at Station 7 and 7 at Station 9) during the months April through July and obtained a total of 1072 larvae (Table 4), which is less than last year (1751). The fish larvae are sometimes too damaged to distinguish at the species level, thus some of the counts are only to the genus level. The percent of the catch identified to the Family Clupeidae (but not further) was 35.45%. Of the Clupeidae that could be identified to the species level, Alewife was the most dominant species with 19.68% of the catch. All clupeids together constituted 90.49% of the catch. Other abundant clupeids were Gizzard Shad at 19.40%, Blueback Herring at 12.41%, Hickory Shad at 3.08% and American Shad at 0.47%. The most dominant non-clupeid species in the catch was White Perch with 1.77% of the catch. Other species somewhat abundant in the ichthyoplankton samples were sunfishes, together at 1.78% of the catch, and Inland Silverside at 1.49%. A total of at least 13 species were identified.

Table 4. The number of larval fishes collected in Gunston Cove and the Potomac River in 2018.

Scientific Name	Common Name	7	9	Total	% of Total
Alosa aestivalis	Blueback Herring	27	106	133	12.41
Alosa mediocris	Hickory Shad	25	8	33	3.08
Alosa pseudoharengus	Alewife	75	136	211	19.68
Alosa sapidissima	American Shad	4	1	5	0.47
Carpiodes cyprinus	Quillback	0	1	1	0.09
Clupeidae	unk. clupeid species	156	224	380	35.45
Cyprinus carpio	Carp	0	0	0	0.00
Dorosoma cepedianum	Gizzard Shad	43	165	208	19.40
Eggs	eggs	34	6	40	3.73
Erimyzon oblongus	Creek Chubsucker	0	1	1	0.09
Lepomis gibbosus	Pumpkinseed	2	0	2	0.19
Lepomis sp.	unk. sunfish	13	4	17	1.59
Menidia beryllina	Inland Silverside	15	1	16	1.49
Morone americana	White Perch	3	16	19	1.77
Notropis hudsonius	Spottail Shiner	0	1	1	0.09
Perca flavescens	Yellow Perch	1	0	1	0.09
Unidentified	unidentified	3	1	4	0.37
Total		**401**	**671**	**1072**	**100**

The mean density of larvae, which takes the volume of water sampled into account over the time sampled, is shown in Figure 66 and 67. Clupeid larvae in Figure 66 include Blueback Herring, Hickory Shad, Alewife, American shad, and Gizzard Shad. These have similar spawning patterns so they are lumped into one group for this analysis. Clupeid larvae showed a distinct peak early May (Figure 66), which follows the spring spawning run of herring and shad. The abundance of other larvae than Clupeids was lower, and had peak right early may as well, plus a larger peak at the start of July (Figure 67). This is a different pattern as previous years, since larval density tends to taper off as the summer progresses. The peak was caused by 16 Inland Silverside specimens. The other larvae included all other taxa listed in Table 4.

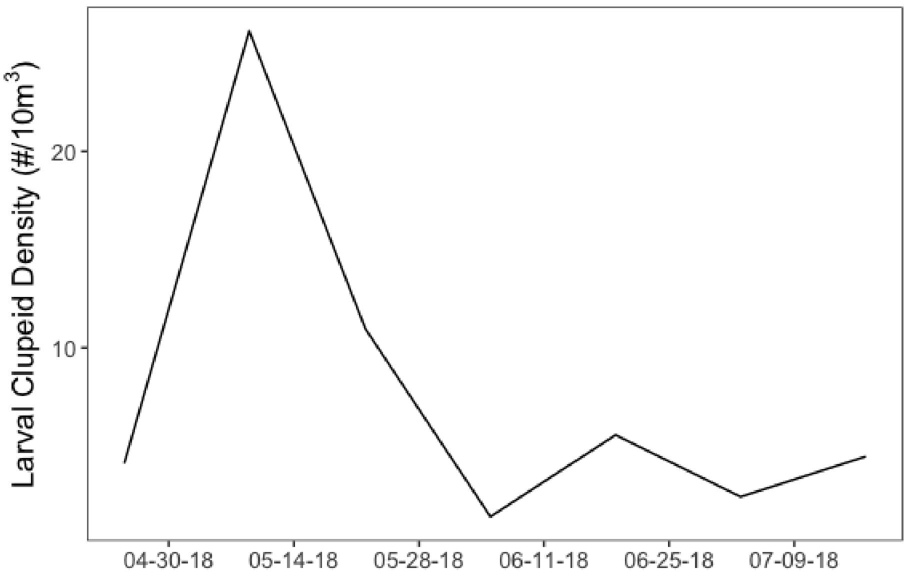


Figure 66. Clupeid larvae, mean density (abundance per 10m^3).

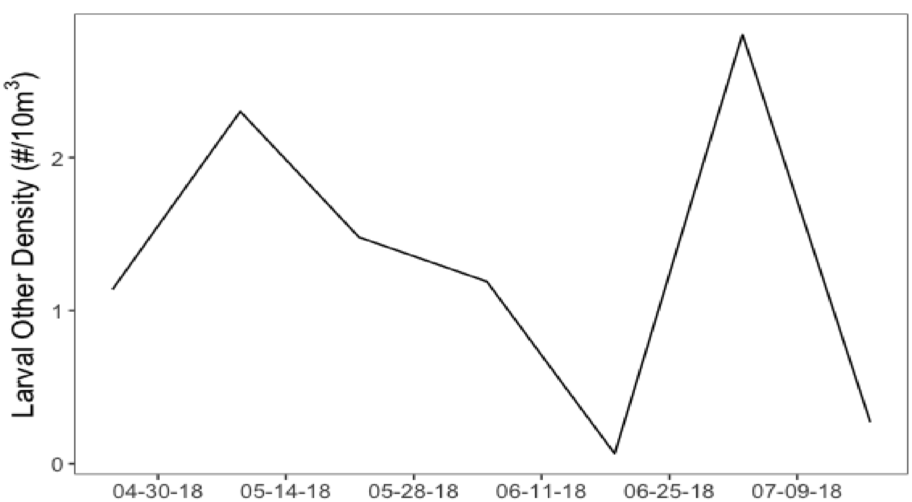


Figure 67. All other larvae, mean density (abundance per 10m^3)

F. Adult and juvenile fishes – 2018

Trawls

Trawl sampling was conducted between April 21 and September 21 at station 7, 9, and 10. These three fixed stations have been sampled continuously since the inception of the survey. Unlike other years, we were able to sample station 10 for the entire sampling season because SAV growth was unusually low. A total of 3296 fishes comprising 23 species were collected in all trawl samples combined (Table 5). This is more than previous years, likely because the lack of SAV increases the catchability of the fishes with a trawl, and because we were able to continue trawling at all station until the end of the season, resulting in more units of effort. The most dominant species of the fish collected was White Perch (55.64%, numerically). Dominance of White Perch in the trawls was lower than 2017, but similar to previous years. Other abundant taxa included Spottail Shiner (18.14%), Tessellated Darter (12.71%), Blue Catfish (3.16%), Pumpkinseed (2.82%), Banded Killifish (1.49%), and *Alosa* sp. (1.30%). Other species were observed sporadically and at low abundances, constituting less than 1% of the total catch per species (Tables 5 and 6).

The dominant migratory species, White Perch, was ubiquitous occurring at all stations on every sampling date (Tables 6 and 7). In the spring, adult White Perch were primarily caught in the nets while later in the summer juveniles dominated. A peak in abundance for White Perch was early July (Table 6). Spottail shiner was ubiquitous throughout the sampling season as well; in low numbers in spring and early summer, quickly going up to a peak mid-June, which numbers remaining high until the end of August.

Table 5. Adult and Juvenile Fish Collected by Trawling. Gunston Cove Study - 2018.

Scientific Name	Common Name	Abundance	Percent
Morone americana	White Perch	1834	55.64
Notropis hudsonius	Spottail Shiner	598	18.14
Etheostoma olmstedi	Tessellated Darter	419	12.71
Ictalurus furcatus	Blue Catfish	104	3.16
Lepomis gibbosus	Pumpkinseed	93	2.82
Fundulus diaphanus	Banded Killifish	49	1.49
Alosa sp.	unk. *Alosa* species	43	1.30
Lepomis macrochirus	Bluegill	30	0.91
Perca flavescens	Yellow Perch	27	0.82
Ameiurus nebulosus	Brown Bullhead	23	0.70
Ameiurus catus	White Bullhead	14	0.42
Lepomis sp.	unk. sunfish	13	0.39
Carassius auratus	Goldfish	9	0.27
Hybognathus regius	Eastern Silvery Minnow	8	0.24
Alosa pseudoharengus	Alewife	7	0.21
Cyprinus carpio	Carp	6	0.18
Lepomis microlophus	Redear Sunfish	5	0.15

Pomoxis nigromaculatus	Black Crappie	5	0.15
Dorosoma cepedianum	Gizzard Shad	4	0.12
Enneacanthus gloriosus	Bluespotted Sunfish	2	0.06
Alosa mediocris	Hickory Shad	1	0.03
Micropterus dolomieu	Smallmouth Bass	1	0.03
Morone saxatilis	Striped Bass	1	0.03
Total		**3296**	**100.00**

Table 6. Adult and Juvenile Fish Collected by Trawling. Gunston Cove Study - 2018.

Scientific Name	**Common Name**	**04-17**	**05-08**	**05-22**	**06-05**	**06-19**	**07-10**	**07-27**	**08-07**	**08-21**	**09-21**	**Total**
Alosa mediocris	Hickory Shad	0	0	0	0	1	0	0	0	0	0	1
Alosa pseudoharengus	Alewife	0	0	0	0	0	7	0	0	0	0	7
Alosa sp.	unk. *Alosa* species	0	0	0	13	6	5	5	7	7	0	43
Ameiurus catus	White Bullhead	0	0	6	1	0	0	6	1	0	0	14
Ameiurus nebulosus	Brown Bullhead	10	0	3	5	0	0	4	0	0	1	23
Carassius auratus	Goldfish	0	0	3	3	0	0	2	1	0	0	9
Cyprinus carpio	Carp	2	1	2	0	0	0	0	1	0	0	6
Dorosoma cepedianum	Gizzard Shad	0	0	0	0	0	0	0	3	1	0	4
Enneacanthus gloriosus	Bluespotted Sunfish	0	0	0	2	0	0	0	0	0	0	2
Etheostoma olmstedi	Tessellated Darter	16	7	0	25	58	74	124	62	12	41	419
Fundulus diaphanus	Banded Killifish	0	0	3	4	7	0	0	2	0	33	49
Hybognathus regius	Eastern Silvery Minnow	0	1	1	0	0	2	0	4	0	0	8
Ictalurus furcatus	Blue Catfish	1	0	16	0	15	5	35	7	5	20	104
Lepomis gibbosus	Pumpkinseed	3	3	21	19	4	9	6	6	2	20	93
Lepomis macrochirus	Bluegill	2	1	7	4	7	0	0	2	1	6	30
Lepomis microlophus	Redear Sunfish	0	0	1	1	3	0	0	0	0	0	5
Lepomis sp.	unk. sunfish	0	0	0	0	0	2	1	10	0	0	13
Micropterus dolomieu	Smallmouth Bass	0	0	0	0	0	0	1	0	0	0	1
Morone americana	White Perch	43	111	22	14	389	420	147	330	202	156	1834
Morone saxatilis	Striped Bass	0	1	0	0	0	0	0	0	0	0	1
Notropis hudsonius	Spottail Shiner	7	4	5	13	176	175	29	120	41	28	598
Perca flavescens	Yellow Perch	1	6	5	2	5	2	2	0	1	3	27
Pomoxis nigromaculatus	Black Crappie	0	0	3	1	0	1	0	0	0	0	5
Total		**85**	**135**	**98**	**107**	**671**	**702**	**362**	**556**	**272**	**308**	**3296**

In total numbers and species richness of fish, station 7 dominated the other stations by far with 1997 individuals from 23 species (Table 7, Figure 68a). Stations 9 and 10 had 502 individuals from 11 species and 797 individuals from 19 species, respectively (Table 7), which is a lot more (about 6x) than last year. Station 10 showed the highest evenness of the catch (68b). Station 9 samples the open water of the mainstem Potomac and thereby doesn't sample preferred habitat such as the littoral zone or the bottom. A notable other species collected in high abundance in station 9 is Blue Catfish, which is an invasive piscivorous species. Two Blue Catfish were collected in the cove as well; one in station 7 and one in station 10. This is a very small portion of the total catch, but an indication that they don't stick to the mainstem as seemed to have been the case in previous years (last year was the first year two were found in station 7). A high number of White Perch was collected. While ubiquitous, most were collected in the Cove (station 7) in mid-summer (Table 6, Figure 69a). Other taxa collected in high abundance in station 7 were Spottail Shiner (373 specimens) and Tessellated Darter (225 specimens). When looking at relative abundance over season can be seen that the composition of the catch is very similar between months, and that the main monthly difference is total abundance of the catch with a peak mid-summer (Figure 69a and b).

White Perch (*Morone americana*), the most common fish in the open waters of Gunston Cove, continues to be an important commercial and popular game fish. Adults grow to over 30 cm long. Sexual maturity begins the second year at lengths greater than 9 cm. As juveniles, they feed on zooplankton and macrobenthos, but as they get larger they consume fish as well.

Spottail Shiner (*Notropis hudsonius*), a member of the minnow family, is moderately abundant in the open water and along the shore. Spawning occurs throughout the warmer months. It reaches sexual maturity at about 5.5 cm and may attain a length of 10 cm. They feed primarily on benthic invertebrates and occasionally on algae and plants.

Trawling collects fish that are located in the open water near the bottom. Due to the shallowness of Gunston Cove, the volume collected is a substantial part of the water column. However, in the river channel, the near bottom habitat through which the trawl moves is only a small portion of the water column. Fishes tend to concentrate near the bottom or along shorelines rather than in the upper portion of the open water.

Table 7. Adult and Juvenile Fish Collected by Trawling. Gunston Cove Study – 2018.

Scientific Name	**Common Name**	**7**	**9**	**10**
Alosa mediocris	Hickory Shad	1	0	0
Alosa pseudoharengus	Alewife	7	0	0
Alosa sp.	unk. *Alosa* species	28	0	15
Ameiurus catus	White Bullhead	3	10	1
Ameiurus nebulosus	Brown Bullhead	8	8	7
Carassius auratus	Goldfish	5	0	4
Cyprinus carpio	Carp	1	3	2
Dorosoma cepedianum	Gizzard Shad	1	0	3
Enneacanthus gloriosus	Bluespotted Sunfish	0	0	2
Etheostoma olmstedi	Tessellated Darter	225	21	173
Fundulus diaphanus	Banded Killifish	7	0	42
Hybognathus regius	Eastern Silvery Minnow	3	4	1
Ictalurus furcatus	Blue Catfish	1	102	1
Lepomis gibbosus	Pumpkinseed	25	1	67
Lepomis macrochirus	Bluegill	2	0	28
Lepomis microlophus	Redear Sunfish	0	0	5
Lepomis sp.	unk. sunfish	0	0	13
Micropterus dolomieu	Smallmouth Bass	0	1	0
Morone americana	White Perch	1289	332	213
Morone saxatilis	Striped Bass	0	1	0
Notropis hudsonius	Spottail Shiner	373	19	206
Perca flavescens	Yellow Perch	17	0	10
Pomoxis nigromaculatus	Black Crappie	1	0	4
Total		**1997**	**502**	**797**

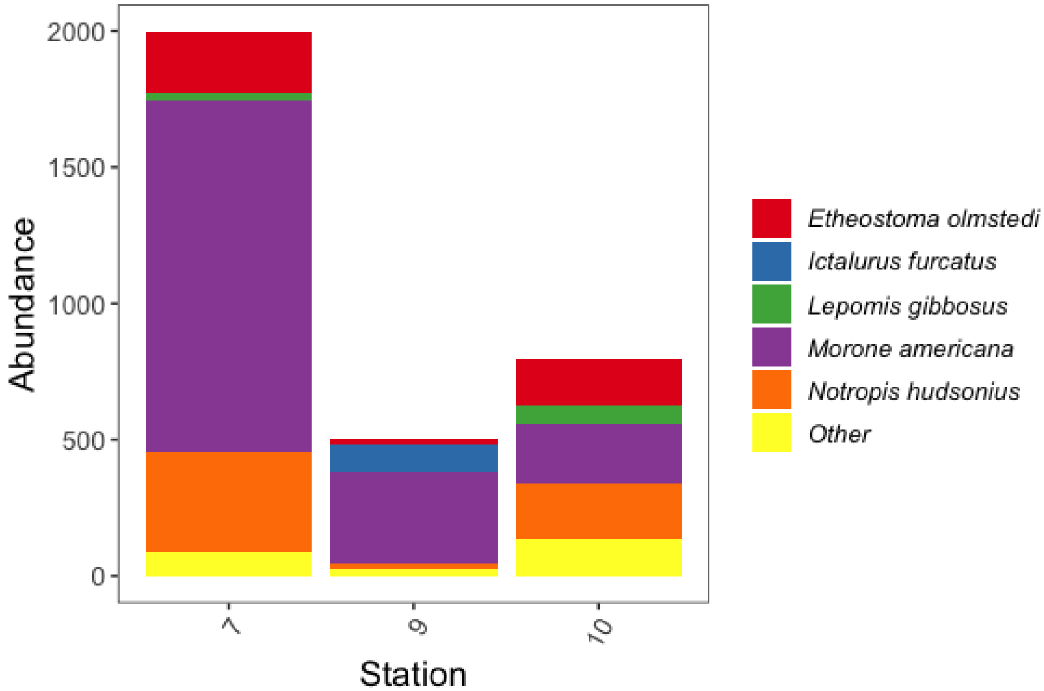


Figure 68a. Adult and Juvenile Fishes Collected by Trawling in 2018. Dominant Species by Station.

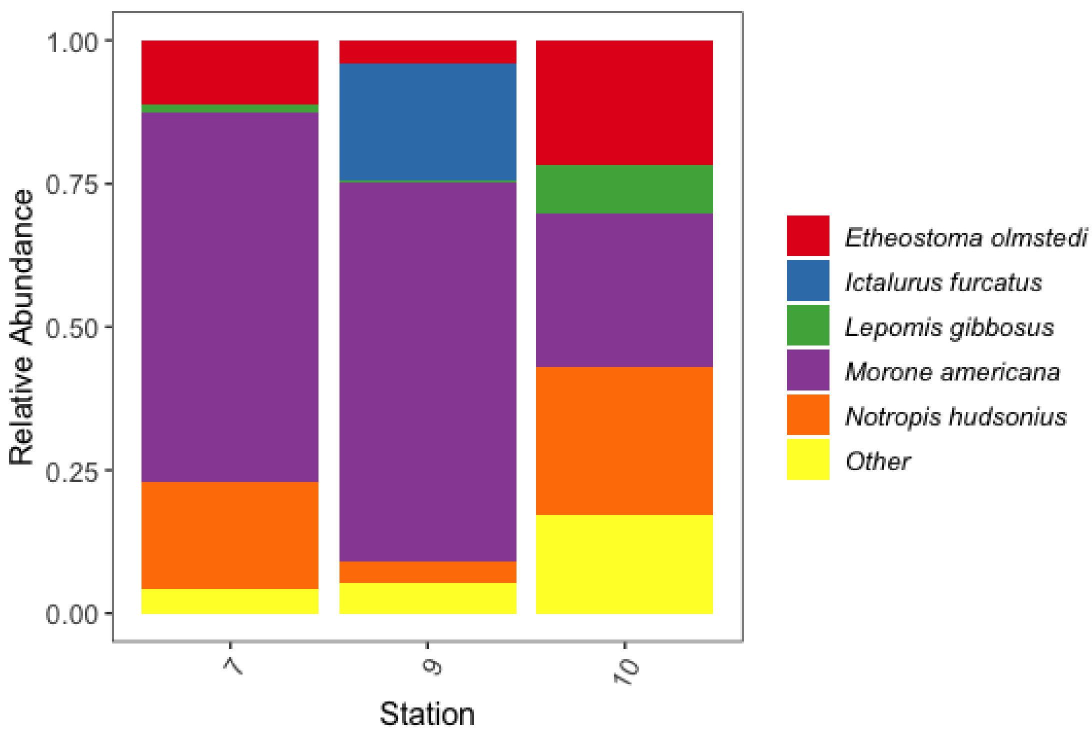


Figure 68b. Relative abundance of Adult and Juvenile Fishes Collected by Trawling in 2018.

The five most abundant species were present in similar proportions over all trawl stations, except for Blue Catfish, which was only abundant in station 9 (Figure 68b). At all stations, White Perch made up the most significant proportion of the total catch. Alosines (herring or shad) were not a dominant group in the trawls this year, though we did see high representation among the larval collections. Station 7 was overall the most productive site. While total catch in Station 10 is higher than in previous years since we could sample all dates in 2018, total catch in Station 7 was still almost three times higher. This means that the usual truncated sampling season of Station 10 is not the main reason why total catch is lower there than in station 7.

When looking at the seasonal trend it is clear that White Perch was the most common species, and dominant in every month (Figure 69a and b). The relative abundance of sunfishes was low compared to earlier years, but were collected throughout the season as well. Spottail Shiner were most abundant in July, with high total and relative abundance in June and August as well. The most productive month was July, which in addition to White Perch saw a high peak in Tessellated Darter. Bay Anchovy, a more saline species of which we sometimes encounter a school and collect in relatively high abundance when that happens, was not collected this season.

Blueback Herring (*Alosa aestivalis*) and Alewife (*Alosa pseudoharengus*) were formerly major commercial species, but are now collapsed stocks. Adults grow to over 30 cm and are found in the coastal ocean. They are anadromous and return to freshwater creeks to spawn in March, April and May. They feed on zooplankton and may eat fish larvae.

Bay Anchovy (*Anchoa mitchilli)* is commonly found in shallow tidal areas but usually in higher salinities. Due to its eurohaline nature, it can occur in freshwater. Feeds mostly on zooplankton, but also on small fishes, gastropods and isopods. They are an important forage fish.

Blue Catfish (*Ictalurus furcatus*) is an introduced species from the Mississippi River basin. They have been intentionally stocked in the James and Rappahannock rivers for food and sport. They have expanding their range and seem to replace white catfish and perhaps also Channel Catfish and bullheads. As larvae, they feed on zooplankton; juveniles and adults mostly on fishes, and on benthos, and detritus.

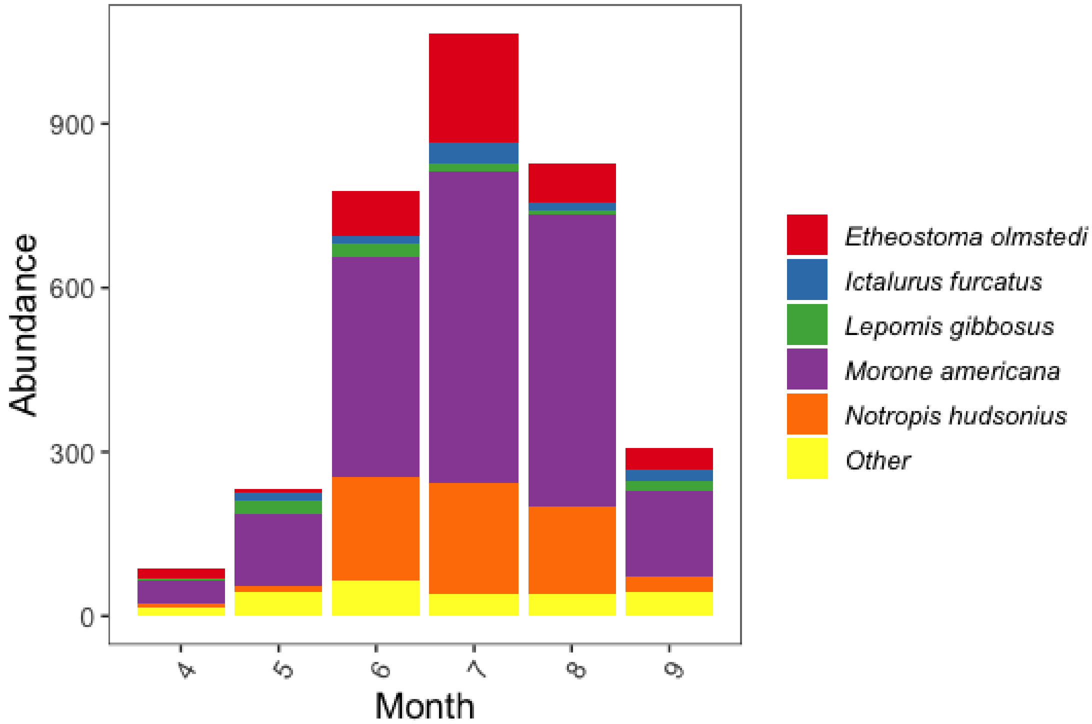


Figure 69a. Adult and Juvenile Fishes Collected by Trawling in 2018. Dominant Species by Month.

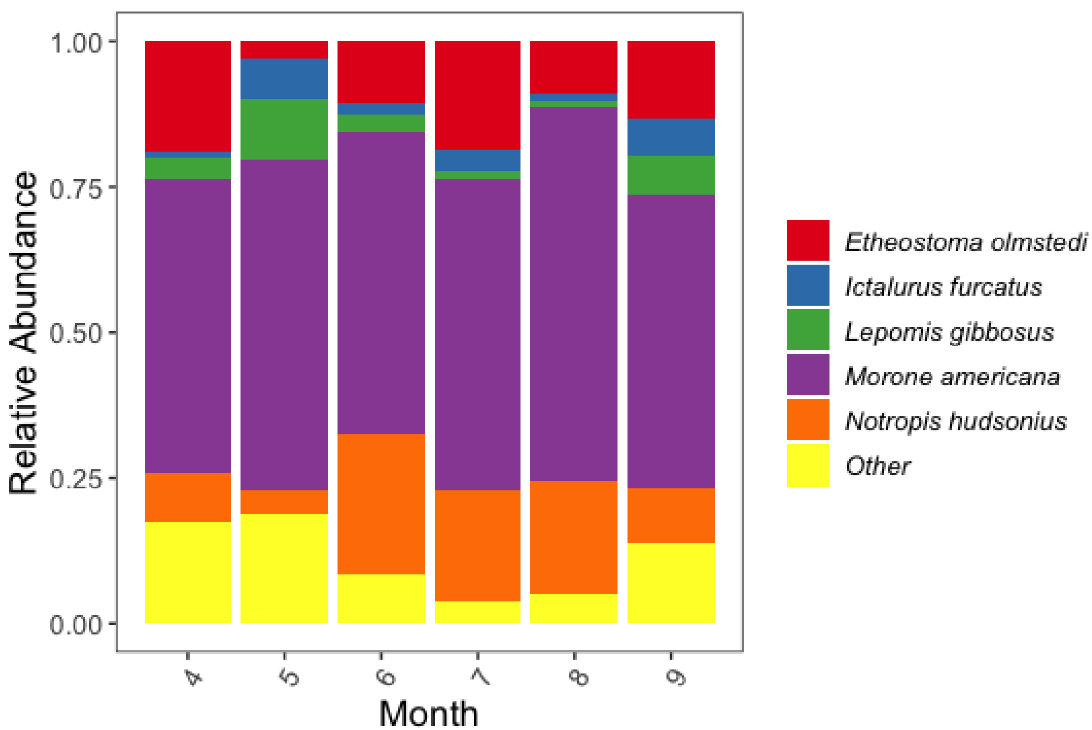


Figure 69b. Relative Abundance for Adult and Juvenile Fishes Collected by Trawling in 2018.

Seines

Seine sampling was conducted approximately semi-monthly at 4 stations between April 17 and September 21. As planned, only one sampling trip per month was performed in April and September. Stations 4, 6, and 11 have been sampled continuously since 1985. Station 4B was added in 2007 to have a continuous seine record when dense SAV impedes seining in 4. Station 4B is a routine station now, also when seining at 4 is possible. This allows for comparison between 4 and 4B. We were able to sample all seine stations throughout the season because of the low SAV cover of 2018.

A total of 40 seine samples were conducted, comprising 4742 fishes of 30 species (Table 8). This is higher than last year, but similar to previous years. Similar to last year, the most dominant species in seine catches was Banded Killifish, with a relative contribution to the catch of 42.62%. The second most common species found were Alosa sp. (herring or shad) who comprised 39.08% of the catch. Other taxa that contributed at least 1% to total abundance include White Perch (3.82%), Tessellated Darter (3.5%), Spottail Shiner (1.96%), Eastern Silvery Minnow (1.64%), Inland Silverside (1.52%), Bluegill (1.22%), and Goldfish (1.16%). Other species occurred at low abundances (Table 8).

Banded Killifish was abundant and present at all sampling dates, with higher abundances in May and June (Table 9, Figure 70). The Herring and Shad appeared in high abundance in the catch in June and then increased late summer with highest abundance in September. Total catch during each sampling date was dominated by these two species in 2018 (Table 9, Figure 70).

Herring and Shad were a more dominant group than Banded Killifish in station 11 and 4, while Banded Killifish was most dominant at 6 and 4B (Table 10, Figure 71). The highest abundances of White Perch was at Station 11. White Perch as well as Herring and Shad are pelagic species, and Station 11 is a beach closest to the mainstem. Total abundance was pretty evenly distributed over the stations and varied from 1134 fish at station 11 to 1438 fish at station 6 (Table 10).

Table 8. Adult and Juvenile Fish Collected by Seining. Gunston Cove Study - 2018.

Scientific Name	Common Name	Abundance	Percent
Fundulus diaphanus	Banded Killifish	2021	42.62
Alosa sp.	unk. *Alosa* species	1853	39.08
Morone americana	White Perch	181	3.82
Etheostoma olmstedi	Tessellated Darter	166	3.50
Notropis hudsonius	Spottail Shiner	93	1.96
Hybognathus regius	Eastern Silvery Minnow	78	1.64
Menidia beryllina	Inland Silverside	72	1.52
Lepomis macrochirus	Bluegill	58	1.22

Carassius auratus	Goldfish	55	1.16
Lepomis gibbosus	Pumpkinseed	40	0.84
Carpiodes cyprinus	Quillback	30	0.63
Dorosoma cepedianum	Gizzard Shad	26	0.55
Notemigonus crysoleucas	Golden Shiner	12	0.25
Fundulus heteroclitus	Mummichog	8	0.17
Lepomis sp.	unk. sunfish	7	0.15
Morone saxatilis	Striped Bass	7	0.15
Pomoxis nigromaculatus	Black Crappie	6	0.13
Micropterus salmoides	Largemouth Bass	5	0.11
Cyprinus carpio	Carp	4	0.08
Gambusia holbrooki	Mosquitofish	4	0.08
Perca flavescens	Yellow Perch	4	0.08
Alosa sapidissima	American Shad	2	0.04
Lepisosteus osseus	Longnose Gar	2	0.04
Pimephales notatus	Bluntnose Minnow	2	0.04
Enneacanthus gloriosus	Bluespotted Sunfish	1	0.02
Ictalurus furcatus	Blue Catfish	1	0.02
Lepomis auritus	Redbreast Sunfish	1	0.02
Micropterus dolomieu	Smallmouth Bass	1	0.02
Semotilus atromaculatus	Creek Chub	1	0.02
Strongylura marina	Atlantic Needlefish	1	0.02
Total		**4742**	**100.00**

Table 9. Adult and Juvenile Fish Collected by Seining. Gunston Cove Study - 2018.

Scientific Name	**Common Name**	**04-17**	**05-08**	**05-22**	**06-05**	**06-19**	**07-10**	**07-27**	**08-07**	**08-21**	**09-21**	**Total**
Alosa sapidissima	American Shad	0	0	0	2	0	0	0	0	0	0	2
Alosa sp.	unk. *Alosa* species	0	0	1	385	25	5	170	348	334	585	1853
Carassius auratus	Goldfish	52	0	0	0	0	0	0	2	0	1	55
Carpiodes cyprinus	Quillback	0	0	7	7	2	4	3	7	0	0	30
Cyprinus carpio	Carp	0	0	1	0	0	0	0	0	3	0	4
Dorosoma cepedianum	Gizzard Shad	2	0	0	0	0	1	16	6	0	1	26
Enneacanthus gloriosus	Bluespotted Sunfish	0	0	0	0	0	1	0	0	0	0	1
Etheostoma olmstedi	Tessellated Darter	4	16	5	1	1	60	21	43	14	1	166
Fundulus diaphanus	Banded Killifish	113	602	163	16	706	124	38	146	48	65	2021
Fundulus heteroclitus	Mummichog	2	2	1	0	0	2	0	1	0	0	8
Gambusia holbrooki	Mosquitofish	0	1	0	0	0	0	2	0	1	0	4
Hybognathus regius	Eastern Silvery Minnow	10	7	0	4	0	0	44	4	7	2	78
Ictalurus furcatus	Blue Catfish	0	0	0	0	0	0	0	1	0	0	1
Lepisosteus osseus	Longnose Gar	0	0	0	0	0	1	1	0	0	0	2
Lepomis auritus	Redbreast Sunfish	0	0	0	0	0	0	0	0	0	1	1
Lepomis gibbosus	Pumpkinseed	9	6	1	3	0	1	1	1	12	6	40
Lepomis macrochirus	Bluegill	21	7	2	0	1	0	2	11	5	9	58
Lepomis sp.	unk. sunfish	0	0	0	0	0	3	0	4	0	0	7
Menidia beryllina	Inland Silverside	35	8	18	4	1	3	2	0	1	0	72
Micropterus dolomieu	Smallmouth Bass	0	0	0	0	0	1	0	0	0	0	1
Micropterus salmoides	Largemouth Bass	1	0	1	0	0	0	2	0	1	0	5
Morone americana	White Perch	2	16	3	0	1	62	21	34	17	25	181
Morone saxatilis	Striped Bass	0	0	0	0	1	0	5	1	0	0	7
Notemigonus crysoleucas	Golden Shiner	6	6	0	0	0	0	0	0	0	0	12
Notropis hudsonius	Spottail Shiner	51	22	1	0	0	1	1	4	2	11	93
Perca flavescens	Yellow Perch	0	0	1	0	0	0	0	2	1	0	4
Pimephales notatus	Bluntnose Minnow	0	2	0	0	0	0	0	0	0	0	2

Pomoxis nigromaculatus	Black Crappie	0	0	0	0	0	1	0	2	2	1	6
Semotilus atromaculatus	Creek Chub	0	0	1	0	0	0	0	0	0	0	1
Strongylura marina	Atlantic Needlefish	0	0	0	0	0	1	0	0	0	0	1
Total		**308**	**695**	**206**	**422**	**738**	**271**	**329**	**617**	**448**	**708**	**4742**

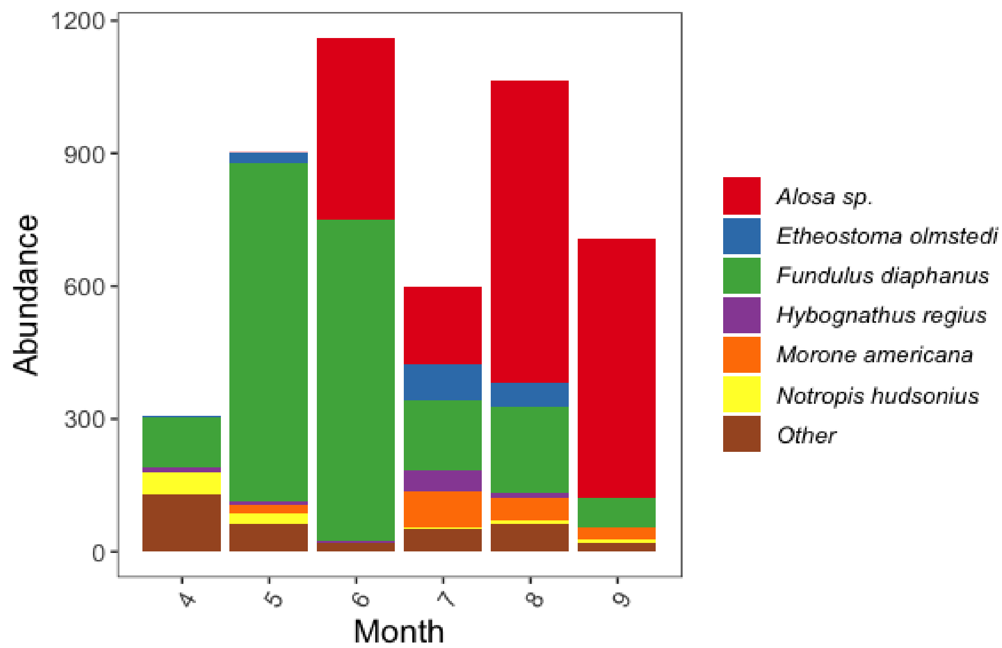


Figure 70. Adult and Juvenile Fish Collected by Seining in 2018. Dominant Species by Month.

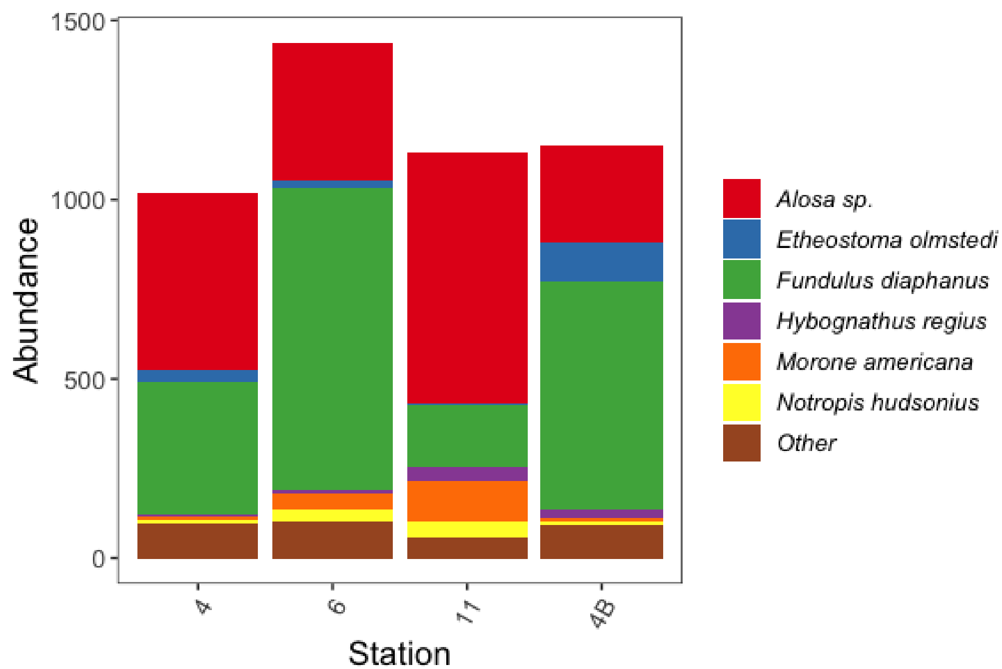


Figure 71. Adult and Juvenile Fishes Collected by Seining in 2018. Dominant Species by Station.

Table 10. Adult and Juvenile Fish Collected by Seining in 2018 per station in Gunston Cove.

Scientific Name	**Common Name**	**4**	**6**	**11**	**4B**
Alosa sapidissima	American Shad	0	0	2	0
Alosa sp.	unk. *Alosa* species	493	387	704	269
Carassius auratus	Goldfish	4	1	0	50
Carpiodes cyprinus	Quillback	0	0	14	16
Cyprinus carpio	Carp	3	1	0	0
Dorosoma cepedianum	Gizzard Shad	4	12	5	5
Enneacanthus gloriosus	Bluespotted Sunfish	0	0	0	1
Etheostoma olmstedi	Tessellated Darter	35	20	2	109
Fundulus diaphanus	Banded Killifish	371	842	173	635
Fundulus heteroclitus	Mummichog	3	5	0	0
Gambusia holbrooki	Mosquitofish	2	1	0	1
Hybognathus regius	Eastern Silvery Minnow	4	9	38	27
Ictalurus furcatus	Blue Catfish	0	0	1	0
Lepisosteus osseus	Longnose Gar	1	0	0	1
Lepomis auritus	Redbreast Sunfish	0	1	0	0
Lepomis gibbosus	Pumpkinseed	24	10	0	6
Lepomis macrochirus	Bluegill	21	36	0	1
Lepomis sp.	unk. sunfish	5	1	0	1
Menidia beryllina	Inland Silverside	21	12	32	7
Micropterus dolomieu	Smallmouth Bass	1	0	0	0
Micropterus salmoides	Largemouth Bass	2	3	0	0
Morone americana	White Perch	9	42	118	12
Morone saxatilis	Striped Bass	0	0	5	2
Notemigonus crysoleucas	Golden Shiner	2	10	0	0
Notropis hudsonius	Spottail Shiner	9	37	40	7
Perca flavescens	Yellow Perch	0	4	0	0
Pimephales notatus	Bluntnose Minnow	0	2	0	0
Pomoxis nigromaculatus	Black Crappie	4	2	0	0
Semotilus atromaculatus	Creek Chub	0	0	0	1
Strongylura marina	Atlantic Needlefish	1	0	0	0
Total		**1019**	**1438**	**1134**	**1151**

Fyke nets

We added fyke nets to the sampling regime in 2012 to better represent the fish community present within SAV beds. As mentioned before there was very low SAV cover in 2018, which also reduces the efficiency of the fyke nets as theybecome very visible to the fishes. This year we collected a total number of 103 specimens of 13 species in the two fyke nets (Station Fyke 1 and Station Fyke 2; Figure 1b; Table 11), which is less than previous years. The fyke nets show a high contribution of sunfishes relative to the other gear types (60.87% of the catch). Other taxa contributing more than 10% of the catch include Inland Silverside at 14.17%, and Tessellated Darter at 10.28%. We collected three Brown Bullheads, which is a native catfish, in the fyke nets this year. Relative high catches in the fyke nets of native catfishes in previous years may be an indication of a spatial shift of native bullheads and catfishes to shallow vegetated habitat, now that Blue Catfish is caught in higher numbers in the open water trawls (in the Potomac mainstem).

Highest abundances were collected in August this year, because of a high abundance of sunfishes that month (Table 12, Figure 72). Sunfishes were the dominant species in all months except in July, when Tessellated Darter was the most dominant species. Of the other abundant species, Inland Silverside had highest abundance from May to July.

Fyke 1 had a higher total catch (58 specimens) than Fyke 2 (45 specimens; Table 13, Figure 73). The higher abundance in Fyke 1 was mostly due to the higher abundance of Inland Silverside in Fyke 1 than in Fyke 2. Overall, the community structure collected with the two fyke nets is very similar; similar community composition with a similar relative contribution to the catch (Table 13, Figure 73).

Table 11. Adult and Juvenile Fish Collected by Fyke Nets. Gunston Cove Study - 2018.

Scientific Name	Common Name	Abundance	Percent
Lepomis gibbosus	Pumpkinseed	34	33.28
Lepomis sp.	unk. sunfish	17	16.01
Menidia beryllina	Inland Silverside	15	14.17
Lepomis macrochirus	Bluegill	11	10.53
Etheostoma olmstedi	Tessellated Darter	11	10.28
Morone americana	White Perch	5	4.82
Ameiurus nebulosus	Brown Bullhead	3	2.91

Perca flavescens	Yellow Perch	2	2.02
Hybognathus regius	Eastern Silvery Minnow	2	1.94
Dorosoma cepedianum	Gizzard Shad	1	1.05
Lepomis cyanellus	Green Sunfish	1	1.05
Micropterus salmoides	Largemouth Bass	1	0.97
Pomoxis nigromaculatus	Black Crappie	1	0.97
Total		**103**	**100.00**

Table 12. Adult and Juvenile Fish Collected by Fyke Nets. Gunston Cove Study - 2018.

Scientific Name	**Common Name**	**04-17**	**05-08**	**05-22**	**06-05**	**06-19**	**07-10**	**07-27**	**08-07**	**08-21**	**09-21**	**Total**
Ameiurus nebulosus	Brown Bullhead	3	0	0	0	0	0	0	0	0	0	3
Dorosoma cepedianum	Gizzard Shad	0	0	0	0	0	0	1	0	0	0	1
Etheostoma olmstedi	Tessellated Darter	0	0	0	0	0	1	8	0	1	1	10
Hybognathus regius	Eastern Silvery Minnow	1	0	1	0	0	0	0	0	0	0	2
Lepomis cyanellus	Green Sunfish	0	0	0	0	0	0	1	0	0	0	1
Lepomis gibbosus	Pumpkinseed	1	7	1	1	12	1	0	8	2	2	32
Lepomis macrochirus	Bluegill	2	7	0	0	1	1	0	0	0	0	11
Lepomis sp.	unk. sunfish	0	0	0	0	0	0	1	11	4	0	17
Menidia beryllina	Inland Silverside	0	0	6	2	2	5	0	0	0	0	15
Micropterus salmoides	Largemouth Bass	1	0	0	0	0	0	0	0	0	0	1
Morone americana	White Perch	3	0	0	0	0	1	0	0	1	0	5
Perca flavescens	Yellow Perch	0	0	0	0	0	1	1	0	0	0	2
Pomoxis nigromaculatus	Black Crappie	1	0	0	0	0	0	0	0	0	0	1
NA	**NA**	**12**	**14**	**8**	**3**	**15**	**10**	**12**	**19**	**8**	**3**	**100**

Table 13. Adult and Juvenile Fish Collected by Fyke Nets. Gunston Cove Study - 2018.

Scientific Name	**Common Name**	**Fyke1**	**Fyke2**
Ameiurus nebulosus	Brown Bullhead	1	2
Dorosoma cepedianum	Gizzard Shad	1	0
Etheostoma olmstedi	Tessellated Darter	4	6
Hybognathus regius	Eastern Silvery Minnow	1	1
Lepomis cyanellus	Green Sunfish	1	0
Lepomis gibbosus	Pumpkinseed	20	15
Lepomis macrochirus	Bluegill	3	8
Lepomis sp.	unk. sunfish	10	7
Menidia beryllina	Inland Silverside	12	3
Micropterus salmoides	Largemouth Bass	1	0
Morone americana	White Perch	4	1
Perca flavescens	Yellow Perch	1	1
Pomoxis nigromaculatus	Black Crappie	0	1
Total		**58**	**45**

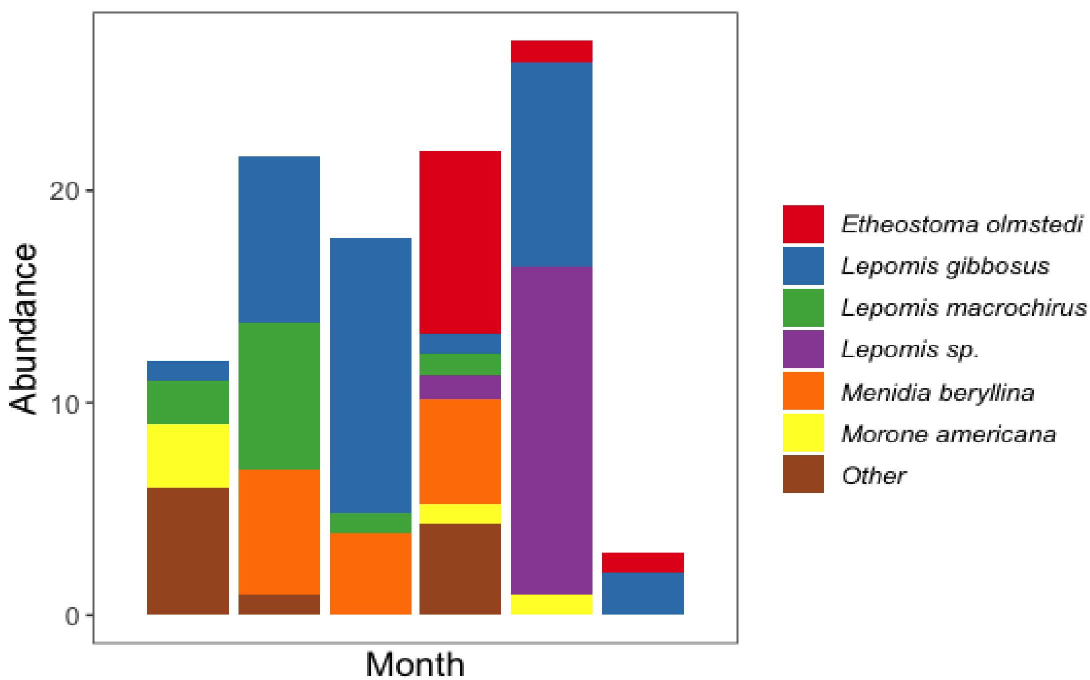


Figure 72. Adult and Juvenile Fish Collected by Fyke Nets. Dominant Species by Month. 2018.

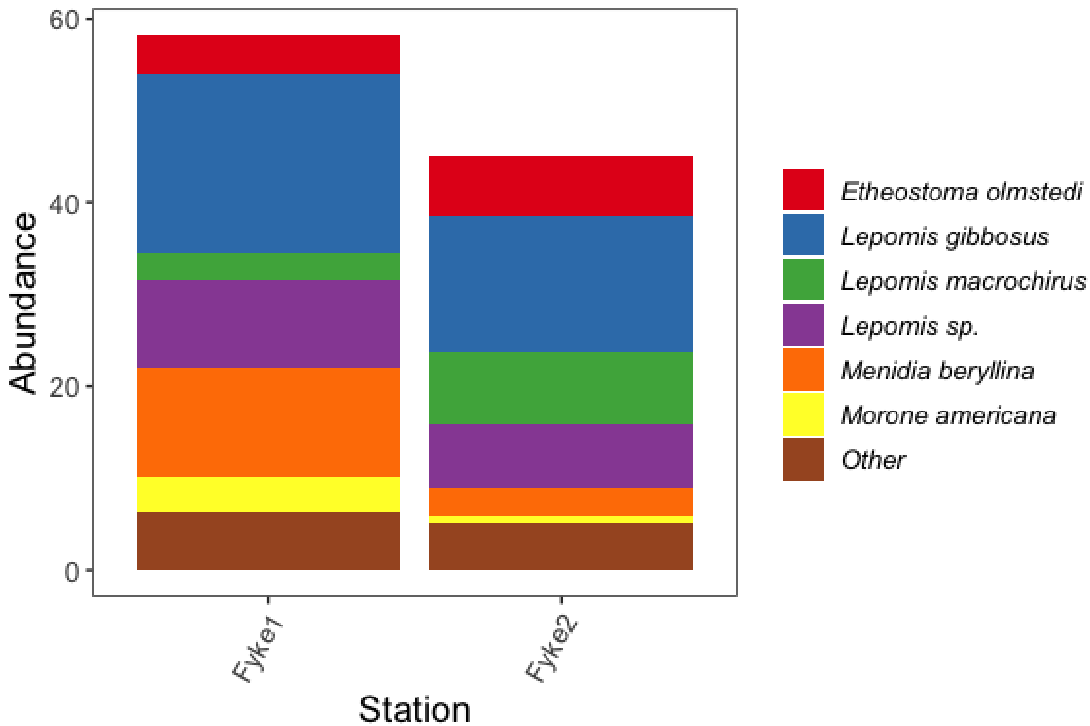


Figure 73. Adult and Juvenile Fishes Collected by Fyke Nets. Dominant Species by Station. 2018.

H. Benthic Macroinvertebrates - 2018

Triplicate petite ponar samples were collected in Gunston Cove proper (Station 7) and in the Potomac River mainstem (Station 9) monthly from May through September (Table 14).

Taxonomic Groups: A total of 14 taxa of benthic macroinvertebrates, belonging to 9 orders and 14 families, were recorded during the survey. Two species were non-native (i.e., the Asian clam, *Corbicula fluminea*, and the Japanese mystery snail, *Cipangopaludina japonica*). Annelid worms (including Oligochaetes and Polychaetes) were found in high numbers (total N = 2563) at each site over all dates. Overall, they accounted for 87% of all benthic organisms found. Oligochaetes were the dominant taxonomic group, accounting for 99% of individuals. Crustaceans (including Gammarid amphipods and isopods) were the second highest in abundance across sites and dates, accounting for 5.7% of all individuals (N = 167). Gammarid amphipods (scuds) dominated this group, accounting for 69% of all crustaceans observed.

The remainder of the taxonomic groups accounted for minor components of the overall diversity. These included Bivalvia (N = 110; 3.7% of total abundance), Gastropods (N = 7; 0.2%), and Insecta (N = 101; 3.4%). The bivalve group was composed of only two taxonomic groups, namely the fingernail clams from the family Sphaeriidae (4.5%) and by the invasive Asian clam, *Corbicula fluminea* (95.5%). The gastropod (i.e., snails) group was composed of taxa from

Viviparidae and Pleuroceridae. The most dominant family was Viviparidae, accounting for 85.7% of all gastropods found. Insects were dominated by Chironomids (midges), which accounted for 98% of all insects, but single representatives of the Chaoboridae (phantom midges) and Caenidae (mayflies) were also found.

Spatial trends: The total abundance of organisms was significantly higher at GC9 in the Potomac mainstem as compared to the site within Gunston Cove (GC7) (Figure 74).
Both sites were dominated by Annelida, driven by high abundances of Oligochaeta. Crustaceans (mostly Gammarid amphipods) played a secondary role at GC9, but were very minor at GC7 (Figure BR2). Bivalves were also observed consistently at GC9. The only taxa besides Annelida that was apparent at GC7 was Insecta (mostly Chironomids). Site CG9 had a higher diversity of taxa (N = 12) than GC7 (N = 6), likely due to differences in sediment and flow characteristics.

Temporal trends: There was a significant difference in total benthic macroinvertebrate abundance between months when GC7 and GC9 were combined with highest densities in June and August (Figure 74). Since GC9 had much higher numbers, the overall pattern was driven by the GC9 seasonal pattern. At GC7 benthic invertebrates peaked in June and declines for the remainder of the year. Across the months, Annelids (mostly Oligochaetes) were the dominant taxa, but had highest abundances at GC7 in June and in August at GC9 (Figure 75). Crustaceans (mostly Gammarid amphipods) also contributed consistently at GC9. Bivalves were greatest in abundance in July, up to 41 individuals/replicate at GC9. Insecta were never a dominant group during this sampling, but highest abundances across all sites occurred during May, June and July at GC7 and highest abundances during July and August at GC9. There was no obvious temporal trend in gastropod abundances due to low numbers collected. Overall, larger increases in abundances over the sampling period for many of the taxa described above are in direct relation to seasonal temperature fluctuations, appearance of structured habitat later in the summer (i.e., submerged aquatic vegetation) and recruitment.

Table 14. Gunston Cove Sites sampled, listed from May to September 2018. Three replicate petite ponar grabs were conducted at each site. Total, average, range, and standard deviation (SD) are listed for the abundance of benthic macroinvertebrates.

Month	Site	Total	Average	Range	SD ±
May	GC 7	84	28	12-38	14.0
	GC 9	190	63	38-96	29.7
June	GC 7	226	75	31-139	56.5
	GC 9	586	195	132-231	55.0
July	GC 7	148	49	28-76	24.4
	GC 9	532	177	103-263	80.6
August	GC 7	106	35	24-52	14.7
	GC 9	929	310	183-452	135.2
September	GC 7	48	16	2-26	12.5
	GC 9	201	67	2-126	61.7

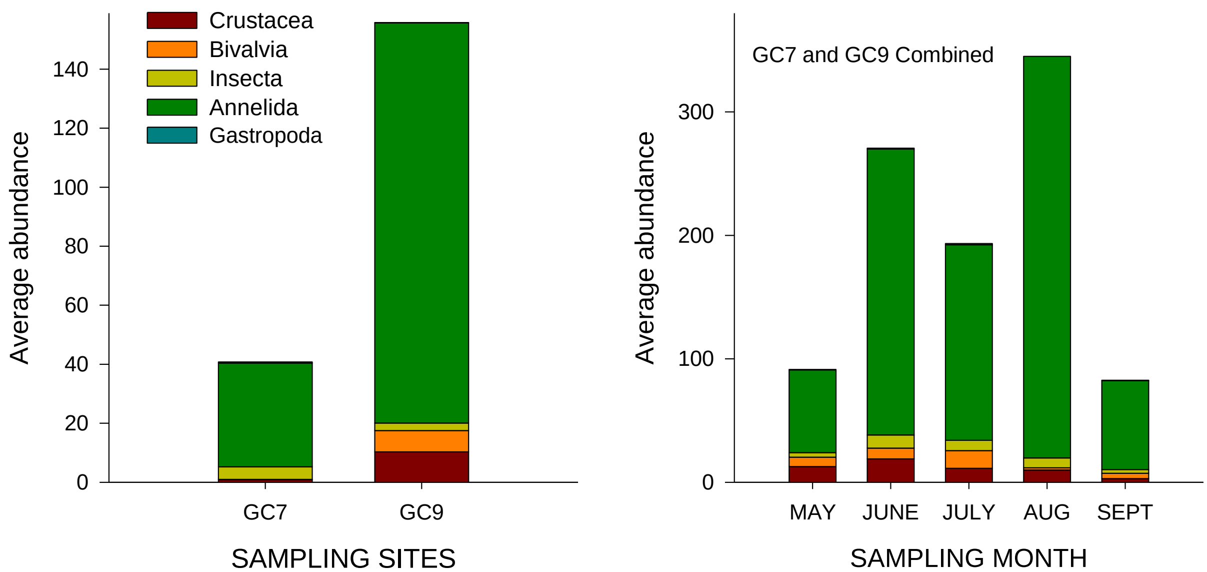


Figure 74. Average abundance of benthic macroinvertebrates per petit ponar sample by Station (left) and Month (right).

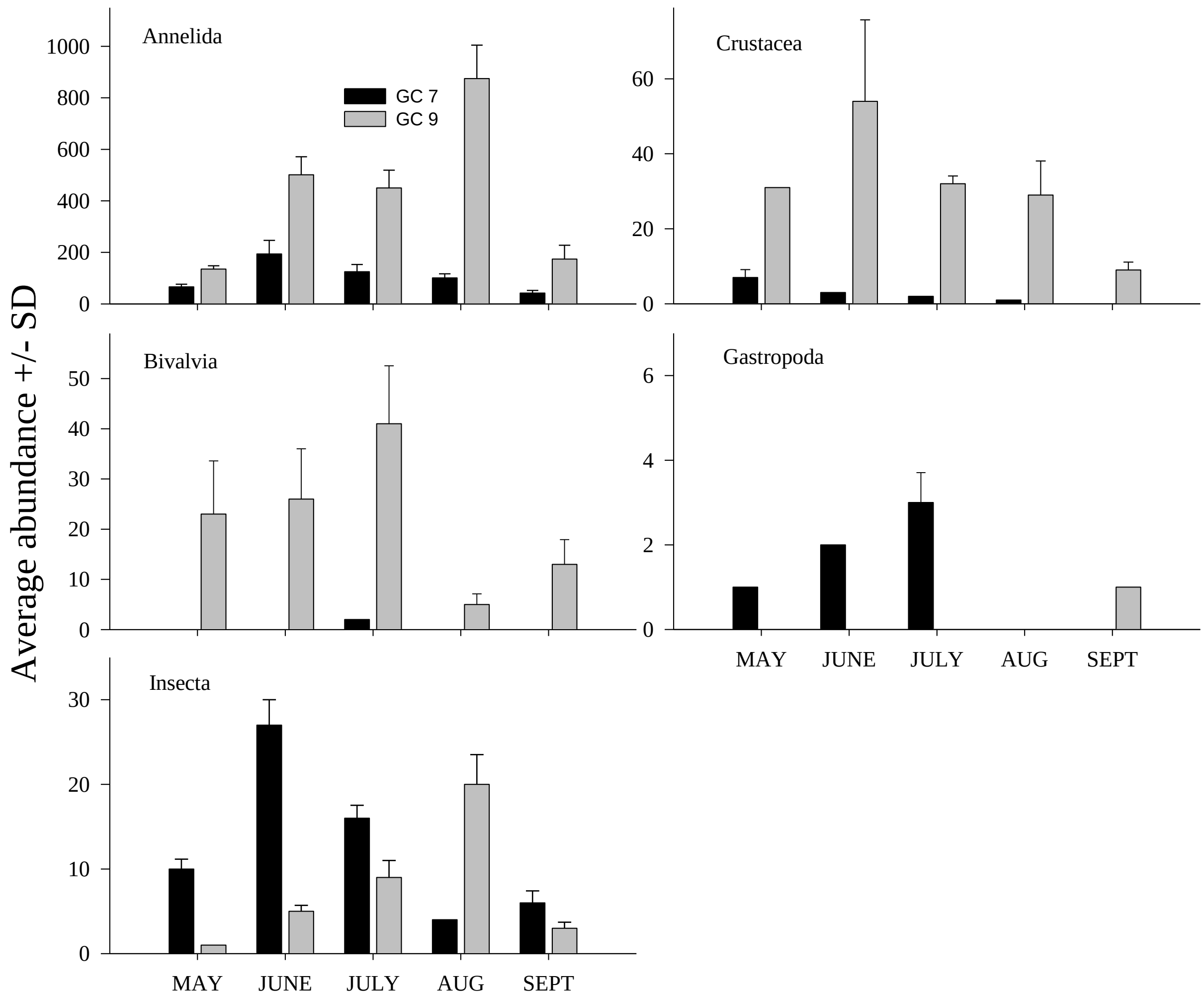


Figure 75. Average abundance (# per ponar ± standard deviation) of benthic macroinvertebrate taxa from three replicate petite ponar samples separated by site, month, and taxonomic group. Note different y-axes.

Community comparisons: To investigate differences in benthic macroinvertebrate community composition, abundance of taxa (down to species level in some cases, N=14 taxa) was fourth-root-transformed to decrease the importance of very abundant taxa. Transformed values were used to create a resemblance matrix using S17 Bray–Curtis similarity index (Bray & Curtis, 1957). These data were compared using site identification and month as factors, and non-metric multidimensional scaling plots (MDS) were generated to visualize differences. A permutational multivariate analysis of variance (PERMANOVA) was used to determine whether significant differences in taxa assemblages existed between sites, months, and the interaction between sites and months. SIMPER analysis was conducted on the fourth-root-transformed data to determine which taxa were driving the differences observed. PERMANOVA, MDS and SIMPER analyses were performed using PRIMER 6 (Clarke & Gorley, 2006).

MDS results (Figure 76) showed a clear separation between all samples collected at GC7 (Gunston Cove) which clustered in the upper left half of the plot and those from GC9 (Potomac mainstem) which clustered in the lower right half of the plot. The two taxa groups contributing most to the dissimilarity between sites were Oligochaeta and *Corbicula* (both higher in GC9). Differences between June and September ($t = 1.79$, $p = 0.04$) and July and September ($t = 1.78$, $p = 0.046$) drove the significance between months among all site pairwise comparisons. Community differences between these two pairs of months were both driven by higher abundances of Oligochaetes, Chironomidae, and Gammarid amphipods in June and July as compared with September.

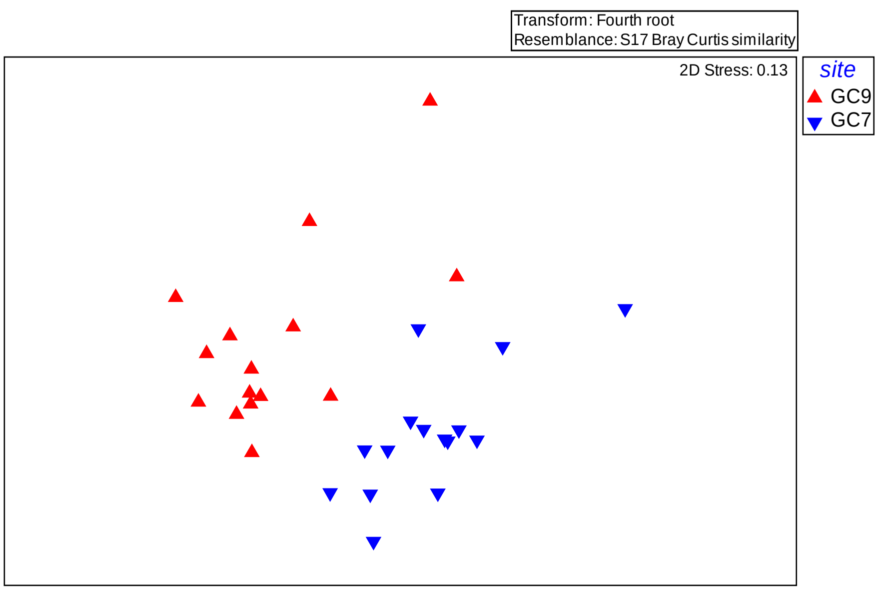


Figure 76. Multidimensional scaling plot of abundances of benthic macroinvertebrate taxa in petite ponar samples sampled in Gunston Cove. Sites that are closer together have more similar communities in terms of both diversity and abundance.

Influence of Habitat on Community Composition: For this analysis, only communities collected in August and September were used. We assigned all materials greater than 5 mm in the petite ponar sample to one of three categories: leaves/woody debris, mollusc shells, or submerged aquatic vegetation and calculated the percent contribution of each category to the overall habitat (Table 15). At GC9 the macroinvertebrate abundance was highly correlated with the type of large particles available; as the percent shells increases and the percent organic matter decreases, the abundance and taxa richness decreases (Table 15). At GC7 there was no relationship between large particle type and total abundance, but this station had variable amounts of large particles present (range of 0 – 82.5% shell and 17.5 – 79.5% leaves or woody debris).

Table 15. Large substrate composition vs. total abundance of benthic macroinvertebrates in individual replicate samples.

	% leaves/wood	% shell	% sav	Tot Abund
GC9Aug1	11.9	88.1	0.0	183
GC9Aug2	29.8	70.2	0.0	452
GC9Aug3	18.3	81.7	0.0	294
GC9Sep1	8.3	91.7	0.0	126
GC9Sep2	6.0	94.0	0.0	72
GC9Sep3	1.3	98.7	0.0	3
GC7Aug1	35.5	64.5	0.0	24
GC7Aug2	79.5	20.5	0.0	30
GC7Aug3	20.2	79.8	0.0	52
GC7Sep1	17.9	82.1	0.0	26
GC7Sep2	17.4	0.0	82.6	20
GC7Sep3	17.5	82.5	0.0	2

H. Submersed Aquatic Vegetation – 2018

The Virginia Institute of Marine Science was unable to conduct its annual aerial SAV study in 2018 due to poor weather condition which resulted in restricted availability of flight times as well as high turbidity.

The distribution of dominant SAV taxa was determined at 33 points in the inner portion of Gunston Cove during datamapping cruises by inserting a garden rake to the bottom, twisting it to collect plants and pulling it on board. The results are summarized in Table 16. *Hydrilla* was found at about half of the sites, but its coverage intensity was generally only moderate. Ceratophyllum and Najas minor were present at only scattered locations and in low density. *Najas guadalupensis* (common water-nymph), *Vallisneria americaas* and *Zosterella dubia* (formerly called *Heteranthera)* which were common in 2017 were not observed at all in 2018.

Table 16. Relative abundance of dominant SAV species determined during data mapping cruise.

Scientific Name	Common Name	Freq (#)	Freq (%)	Avg. Density
Hydrilla verticillata	hydrilla	17	51.5	1.15
Ceratophyllum demersum	coontail	3	9.1	0.66
Najas minor	minor naiad	4	12.1	0.63

A total of 33 points were sampled for SAV with a water depth of 2.2 m or less. Frequency (#) is the number of points that contained a particular species of SAV. Frequency (%) is the proportion of points that contained that species. Average density is the average coverage value at those points that contained a particular species. Coverage values ranged from 0.5 (present) to 3 (very abundant).

DISCUSSION

A. 2018 Data

In 2018 air temperature was substantially above average from May through August. Precipitation was above normal for the entire study period and well above normal during May, July and September. The largest daily rainfall total was 10.16 cm on July 21. There were two sampling dates which were preceeded by extended periods of substantial rainfall and subsequent relatively immediate local stream flow input which would be expected to impact water quality and plankton communities in the cove at Station GC7. Between May 13 and May 19, 15.2 cm of rainfall occurred leading up to the May 22 sampling date. The August 7 sampling date was preceeded by 22.4 cm of rainfall between July 21 and August 6. Sampling dates preceeded by little rainfall the previous two weeks included May 9, June 19, and August 21. Rainfall and runoff patterns relative to sampling dataes are shown in Figure 77.

River flows which would directly impact GC9 followed a similar seasonal pattern. From mid April to mid May, river flows were relatively normal (see Figure 2). Beginning on May 15 and continuing through June 28, river flows were substantially elevated, thus potentially impacting GC9 on sampling dates May 22, June 5, and June 19. From July 1 through July 21 a period of decreasing river flows typical of summer was observed. Thus, the July 3 and July 17 sampling dates should not be flow impacted. But flows again become elevated in late July and remained well above normal for the remainder of the study period.

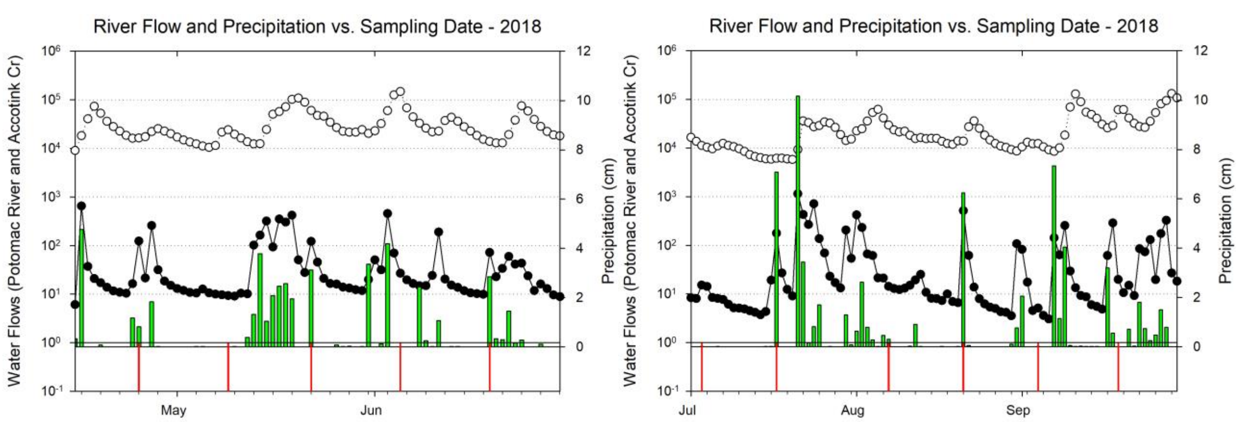


Figure 77. Precipitation (green bars), Accotink Creek flows (solid circles), Potomac River flows (open circles) and water quality/plankton sampling events (red lines at bottom).

Mean water temperature was similar at the two stations with a pronounced dip in late May and a peak of about 30° in early September. Specific conductance declined substantially at both stations in the wake of the late May flow events. There was a gradual rise thorough mid July and a strong, but temporary decline in early August, again apparently flow related. Chloride showed only a strong decline in the cove in May, but little response to other flow events. Dissolved oxygen saturation and concentration (DO) were normally substantially higher in the cove than in the river apparently due to photosynthetic activity of phytoplankton alone, since

SAV was very limited in 2018. River DO's did not vary much in response to flow events. However, there was a dramatic decline in the cove in late May and early June. This was presumably due to a decline in phytoplankton as indicated by a decline in chlorophyll levels in late May and early June. These events recurred again in early August in response to the increased flows during late July and early August. Field pH patterns mirrored those in DO: higher values in the cove than the river and declines in late May and early August due to flushing of phytoplankton.. Total alkalinity was generally higher in the river than in the cove and showed a general increase in spring and early summer to a peak in August (except for unusual values in late July). Water clarity exhibited a strong response to the late May and early August flow events. Secchi disk transparency and light attenuation coefficient were both strongly decreased in late May and early June and turbidity increased at that time. The response to the July flows was not as clearcut.

Ammonia nitrogen was consistently low in the study area during 2017, but all values were below the limits of detection making analysis of any temporal or spatial trends impossible. Un-ionized ammonia probably remained below values that would cause toxicity issues, but exact values were not possible due to the high incidence of non-detects for total ammonia. Nitrate values declined strongly in late May, probably due to the storm flushing. A second decline was observed in July before the late July flushing. This second decline was probably due to uptake by phytoplankton which was increasing strongly during this period in both river and cove. Nitrite showed a midsummer minimum and was not obviously tied to flow events. Organic nitrogen in the cove showed a strong decline in response to the May high flows, but there was no response to the July flows. River organic nitrogen did not seem to be flow related. Total phosphorus was generally somewhat higher at the river station and showed little seasonal change or response to the flow events. Soluble reactive phosphorus was generally higher in the river and declined greatly in late July, perhaps due to phytoplankton uptake during the July bloom. N to P ratio did not show a consistent seasonal pattern, but was generally in the 12-30 range which is still indicative of P limitation of phytoplankton and SAV. BOD was generally higher in the cove than in the river. TSS in the river responded strongly to the May and July flow events by doubling. In the cove a strong response was seen to the July, but not to the May high flows. VSS did not show strong spatial and temporal patterns.

In the cove algal populations as measured by chlorophyll *a* were consistently higher in the cove than in the river and showed a clear response to flow events. Promising values in the spring in the cove were dramtically decreased by the late May flow event. A steady increased followed through mid July. Values in the cove dropped back slightly in early August in response to high July flows and then again in September in response to renewed high flows. In the river early season values were muted, but even those were greatly decreased in late May. The increase in chlorophyll in the river was very strongly curtailed in early August and values only weakly recovered. Total cell density values did not track chlorophyll levels very well. Cell density in the cove was dominated by cyanobacteria, with *Oscillatoria*, *Chroococcus*, and *Anabaena* being the dominants. In the river, cyanobacteria dominanted in most months with diatoms being important in June. The same cyanobacterial genera were dominant. Phytoplankton biovolume tracked chlorophyll a better exhibiting the seasonal pattern of values peaking in late July. Diatoms greatly dominated phytoplankton biovolume with *Melosira* and discoid centrics making the greatest contributions and being responsible for the July peak.

Rotifers continued to be the most numerous zooplankton in 2018. Rotifer densities were unusually high in early May in the cove and the river with *Keratella* dominant in the cove and *Ploesoma* in the river. These values were greatly diminished in late May and early June due to flushing from the high flows. Rotifer populations recovered during June and July attributable to *Brachionus, Filinia*, and *Keratella*. A decline then ensured perhaps due to flushing. In the cove a strong early September peak of *Brachionus* ended the year. *Bosmina*, a small cladoceran was quite abundant in early May and mid July, but dropped just as rapidly during the flow events. . *Diaphanosoma*, a larger cladoceran, was found almost exclusively in mid July in the cove and was apparently eliminated by the late July flow event. *Daphnia* exhibited a similar pattern around the late May flow event, being very common in early May in the cove. *Leptodora* exhibited a small peka in July in the cove before the flows occurred. Copepod nauplii densities exhibited a clear response to the late May and late July flow events suffering large losses in the subsequent samples in each case. The calanoid copepod *Eurytemora* was very abundant in the cove in April and early May, but declined greatly in late May and June. There was a shortlived peak in the river in early July. A second calanoid *Diaptomus* was found at much lower levels. Cyclopoid copepods had a strong maximum in the cove in early May and in the river in late August.

In 2018 ichthyoplankton was dominated by clupeids, most of which were Alewife, Gizzard Shad, and Blueback Herring, and to a lesser extent Hickory Shad, and American Shad. Although clupeids constituted more than 90% of the catch, 13 different species were identified in the ichthyoplankton samples. Of those, White Perch was found in relatively high densities. White Perch was mostly found in the Potomac mainstem, confirming its affinity for open water. Other taxa were found in very low densities similar to the previous year. The highest density of fish larvae occurred at the start of May, which was driven by a high density of Clupeid larvae in combination with relative density of other larvae. The non-clupeid larval density was highest in spring with a second peak in early July, which was Inland Silverside larvae.

Unlike previous years, submerged aquatic vegetation had very low cover, which has an effect on fish sampling. As a result, all trawl and seine stations could be sampled throughout the season, and the fyke nets were not very effective. In trawls, White Perch dominated with 55.6% of the catch, followed by Spottail Shiner and Tessellated Darter. White Perch was found in all months at all stations, with peak abundance in July. More than a hundred invasive Blue Catfishes were collected with the trawl in the river with two additional ones in the cove. While our cove trawl stations were unobstructed by SAV this year, we still found a large disparity between catches of Blue Catfish in the mainstem versus the cove, which supports the theory that Blue Catfish has an affinity for the mainstem, potentially leaving embayments like Gunston Cove to serve as a refuge for native catfishes. We collected thirty-seven native catfishes within Gunston Cove, of which 23 were brown bullhead, and 14 were white bullhead. In general, these species have been on the decline since the invasion of Blue Catfish.

In seines, the most abundant species was Banded Killifish (*Fundulus diaphanus*) which composed 42.6% of seine-collected fish. Banded Killifish was far more abundant in seines than in trawls, which emphasizes the preference of Banded Killifish for the shallow littoral zone (which is the area sampled with a seine, while trawls sample the open water). The abundance peak of Banded Killifish was in May and June. Other taxa with high abundances were Herring and Shad, which together came close to being as abundant as Banded Killifish. Numerous small Alosa juveniles started appearing in the samples in early June, after the spring spawning of river herring and American Shad. This is a good sign for this group of species that has been on the decline coastwide. Abundances remained high throughout the sampling season with a peak in September, which includes the non-anadromous clupeid Gizzard Shad. Other relatively abundant species collected with the seines were White Perch and Tessellated Darter.

Fyke nets were part of the sampling regime again in 2018. The total catch of the fyke nets is smaller than the other gears, and was much smaller than previous years since avoidance by fish is higher when the stationary nets are not hidden by SAV cover. However, it still represents an interesting contribution to the total catch because the composition of the catch in fyke nets is different than the trawls and seines. Sunfishes were the most dominant taxa, with Inland Silverside as the second most abundant species. Sunfishes that could be identified to the species level were represented in order of abundance by Pumpkinseed, Bluegill, and Green Sunfish. Overall catches were low with highest abundance in August.

The coverage of submersed aquatic vegetation (SAV) in 2018 was very limited in contrast to every year since 2004. The major problem seems to be the high turbidity and subsequent low light levels mainly due to inorganic sediments brought in or resuspended by the May flow events. Then this was followed by other flow events in July and September. The exotic plant *Hydrilla* did better than other taxa, but was present in a smaller area and at much lower densities than in previous years. Unfortunately, due to a combination of factors, including poor water clarity in September, VIMS was unable to provide the standard aerial survey which would have documented the full extent of the dieback. As in most previous years, oligochaetes were the most common invertebrates collected in ponar samples in 2018. Amphipods were common at both stations. Chironomids were also common in the cove and bivalves in the river. Multivariate analysis showed a clear and consistent difference between cove benthic communities and those in the river.

B. Water Quality Trends: 1983-2018

To assess long-term trends in water quality, data from 1983 to 2018 were pooled into two data files: one for Mason data and one for Noman Cole laboratory data. Then, subgroups were selected based on season and station. For water quality parameters, we focused on summer (June-September) data as this period is the most stable and often presents the greatest water quality challenges and the highest biological activity and abundances. We examined the cove and river separately with the cove represented by Station 7 and the river by Station 9. We tried several methods for tracking long-term trends, settling on a scatterplot with LOWESS trend line. Each observation in a particular year is plotted as an open circle on the scatterplot. The LOWESS (locally weighted sum of squares) line is drawn by a series of linear regressions moving through the years. We also calculated the Pearson correlation coefficient and performed linear regressions to test for statistical significance of a linear relationship over the entire period of record (Tables 17 and 18). This was similar to the analysis performed in previous reports.

Table 17
Correlation and Linear Regression Coefficients
Water Quality Parameter vs. Year for 1984-2018
GMU Water Quality Data
June-September

	Station 7			Station 9		
Parameter	Corr. Coeff.	Reg. Coeff.	Signif.	Corr. Coeff.	Reg. Coeff.	Signif.
Temperature	0.193	0.053	0.005	0.094	-----	NS
Conductivity, standardized to 25°C	0.121	1.40	0.034	0.005	-----	NS
Dissolved oxygen, mg/L	0.051	-----	NS	0.216	0.026	0.002
Dissolved oxygen, percent saturation	0.029	-----	NS	0.239	0.362	<0.001
Secchi disk depth	0.700	1.71	<0.001	0.299	0.471	<0.001
Light attenuation coefficient	0.668	0.087	<0.001	0.077	-----	NS
pH, Field	0.199	-0.012	0.003	0.205	0.009	0.002
Chlorophyll, depth-integrated	0.619	-3.74	<0.001	0.302	-0.770	<0.001
Chlorophyll, surface	0.607	-3.79	<0.001	0.284	-0.844	<0.001

For Station 7, n=304-323 except pH, Field where n=257 and Light attenuation coefficient where n=241.
For Station 9, n=262-276 except pH, Field where n=224 and Light attenuation coefficient where n=211.

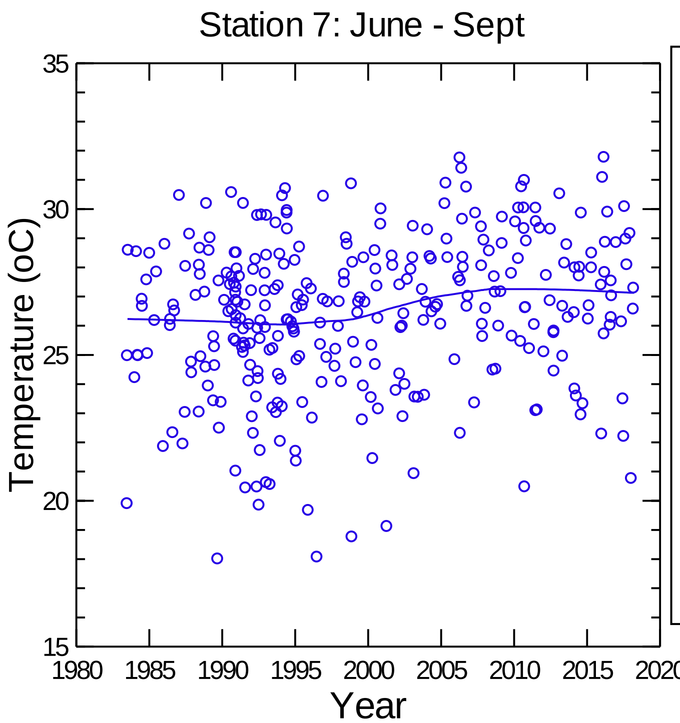
Significance column indicates the probability that a correlation coefficient this large could be due to chance alone. If this probability is greater than 0.05, then NS (not significant) is indicated. Both near surface and near bottom samples included.

Table 18
Correlation and Linear Regression Coefficients
Water Quality Parameter vs. Year for 1983-2018
Fairfax County Environmental Laboratory Data
June-September

	Station 7			Station 9		
Parameter	Corr. Coeff.	Reg. Coeff.	Signif.	Corr. Coeff.	Reg. Coeff.	Signif.
Chloride	0.003	-----	NS	0.052	-----	NS
Lab pH	0.514	-0.034	<0.001	0.333	-0.016	<0.001
Alkalinity	0.096	0.176	0.033	0.338	0.426	<0.001
BOD	0.644	-0.156	<0.001	0.401	-0.043	<0.001
Total Suspended Solids	0.362	-0.890	<0.001	0.193	-0.110	0.003
Volatile Suspended Solids	0.408	-0.577	<0.001	0.377	-0.123	<0.001
Total Phosphorus	0.572	-0.004	<0.001	0.309	-0.001	<0.001
Soluble Reactive Phosphorus	0.095	-0.0001	0.035	0.090	-----	NS
Ammonia Nitrogen	0.314	-0.016	<0.001	0.288	-0.0029	<0.001
Nitrite Nitrogen	0.443	-0.003	<0.001	0.161	-0.001	<0.001
Nitrate Nitrogen	0.578	-0.032	<0.001	0.625	-0.032	<0.001
Organic Nitrogen	0.586	-0.045	<0.001	0.374	-0.012	<0.001
N to P Ratio	0.255	-0.288	<0.001	0.457	-0.455	<0.001

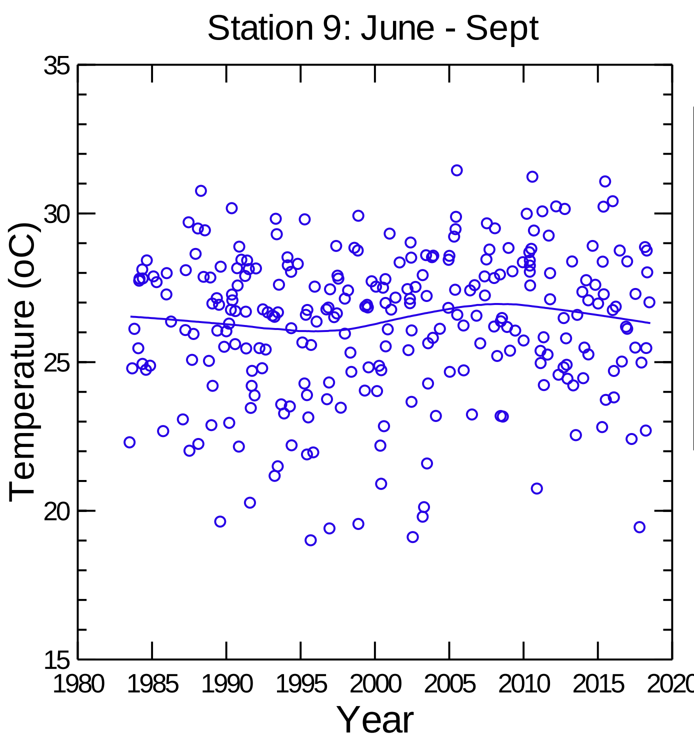
For Station 7, both surface and bottom samples used, n=463-506 except Nitrite Nitrogen where n=428
For Station 9, only surface samples used, n=230-254 except Nitrite Nitrogen where n =215.

Significance column indicates the probability that a correlation coefficient this large could be due to chance alone. If this probability is greater than 0.05, then NS (not significant) is indicated.



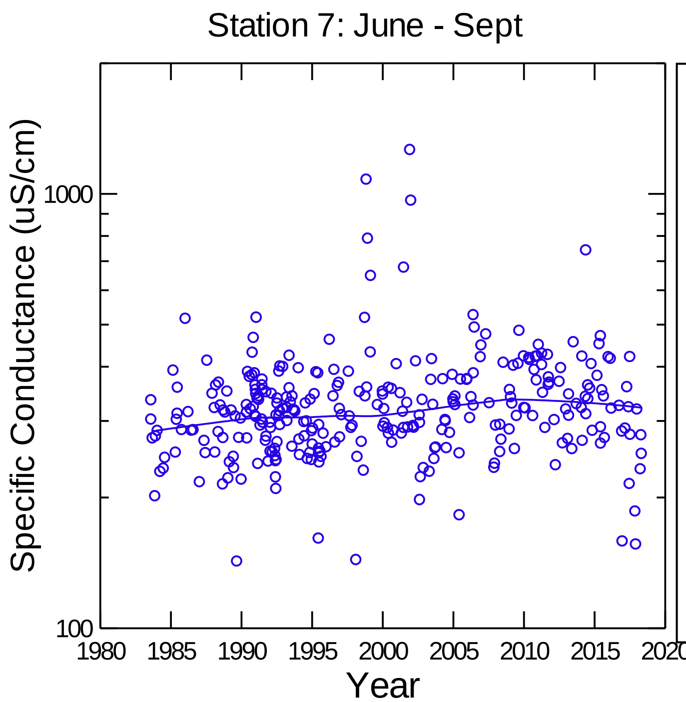
Water temperatures during the summer months generally varied between 20ºC and 30ºC over the study period (Figure 78). The LOWESS curve indicated an average of about 26°C during the period 1984-2000 with a slight upward trend in the last few years to about 27ºC. Linear regression analysis indicated a significant linear trend in water temperature in the cove when the entire period of record is considered (Table 17). The slope of this relationship is 0.05°C/year.

Figure 78. Long term trend in Water Temperature (GMU Field Data). Station 7. Gunston Cove.



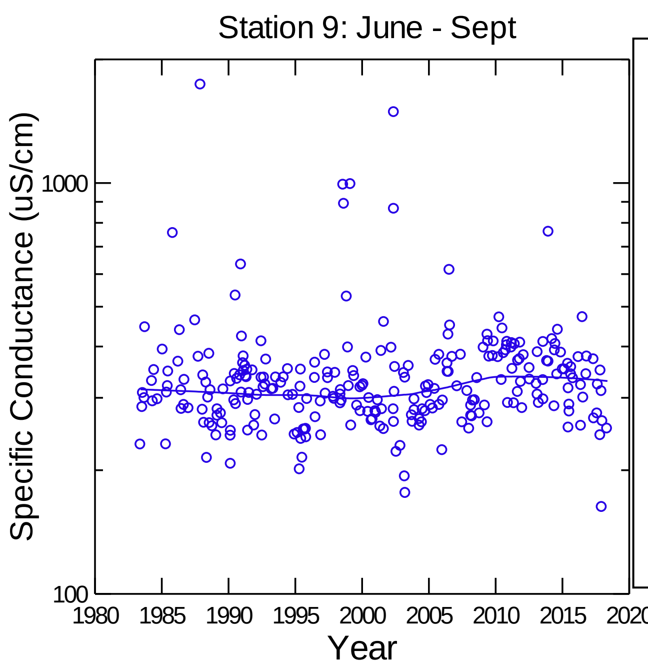
In the river summer temperatures have been similar to those in the cove with fewer readings above 30°C in the river (Figure 79). The long term trend was not significantly different from 0 in the river (Table 17).

Figure 79. Long term trend in Water Temperature (GMU Field Data). Station 9. Gunston Cove.



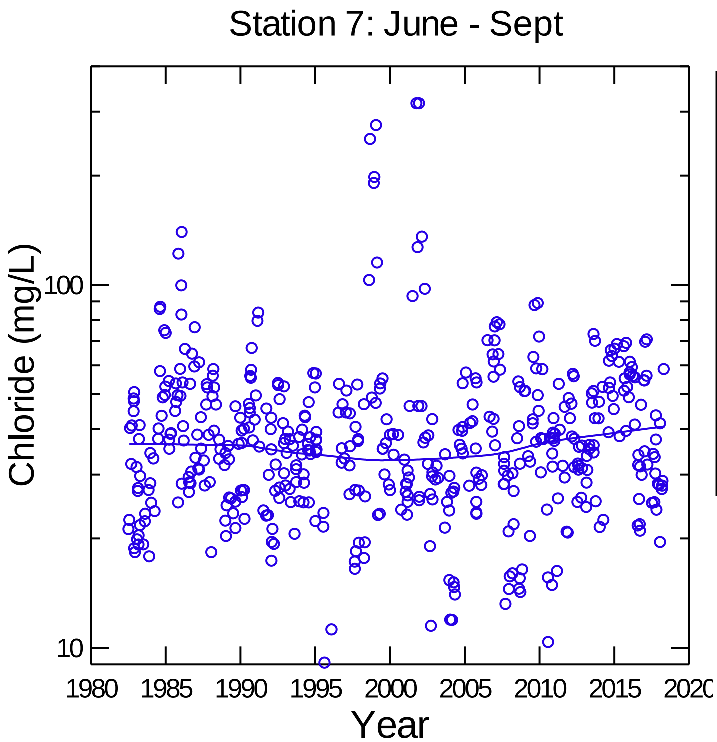
Specific conductance was generally in the range 200-500 µS/cm over the study period (Figure 80). Some significantly higher readings have been observed sporadically. A slight increase in specific conductance was suggested by the LOWESS line over the study period. This was confirmed by linear regression analysis which found a significant linear increase of 1.4 µS/cm per year over the long term study period (Table 17). This would yield a total increase of 49 uS/cm over the entire study period.

Figure 80. Long term trend in Specific Conductance (GMU Field Data). Station 7. Gunston Cove.



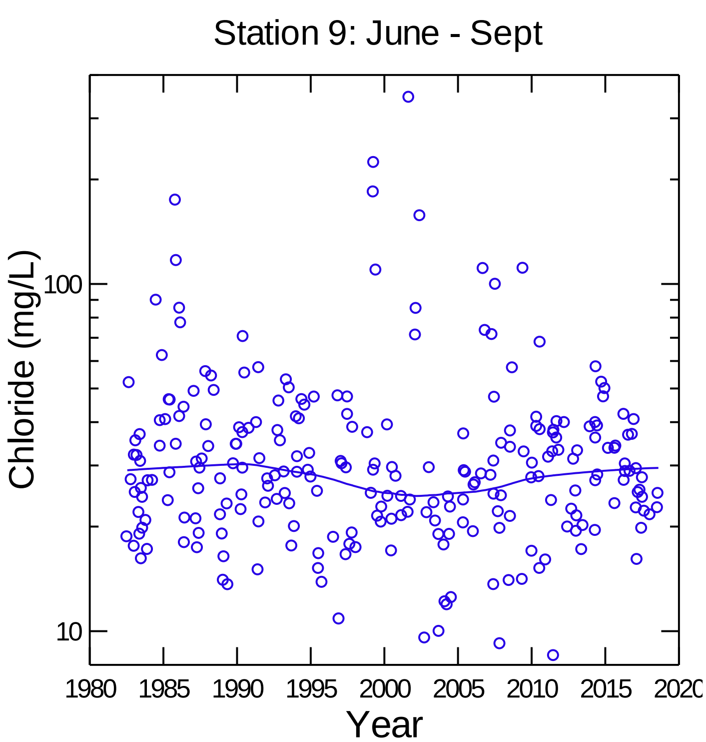
Conductivity values in the river were in the same general range as in the cove (Figure 81). Most values were between 200 and 500 µS/cm with a few much higher values. These higher values are probably attributable to intrusions of brackish water from downstream during years of low river flow. Linear regression did not reveal a significant trend in river conductivity (Table 17). However, the trend line has moved up in recent years from about 300 µS/cm to about 350 µS/cm.

Figure 81. Long term trend in Specific Conductance (GMU Field Data). Station 9. River mainstem.



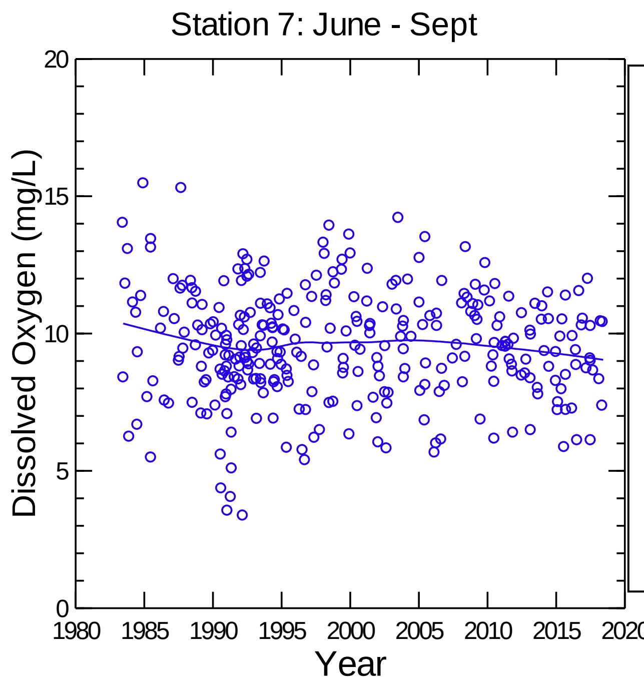
Chloride levels were clustered in a relatively narrow range of 20-60 mg/L for the entire study period (Figure 82). Higher values observed in some years were probably due to the estuarine water intrusions that occur in dry years. The trend line is nearly flat and a linear regression was not statistically significant (Table 18).

Figure 82. Long term trend in Chloride (Fairfax County Lab Data). Station 7. Gunston Cove.



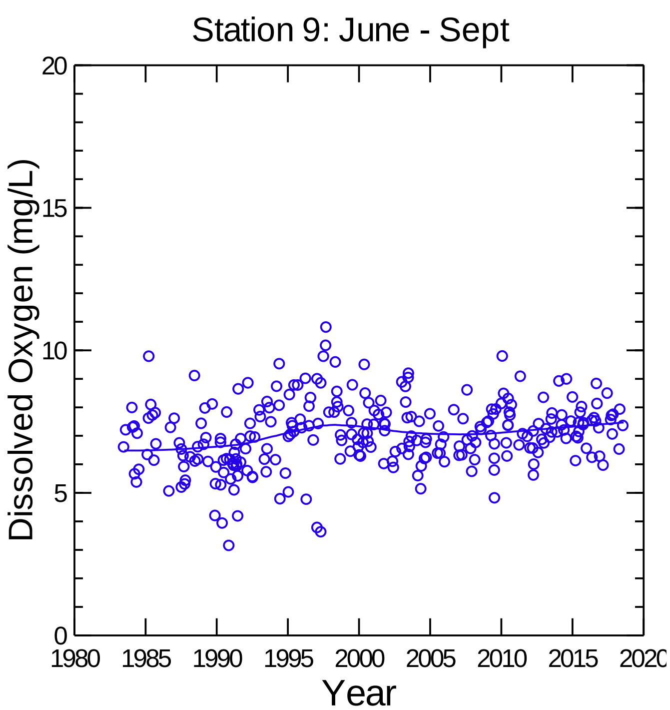
Chloride in the river has been slightly more variable than that in the cove, but in the same general range (Figure 83). The higher readings are again due to brackish water intrusions in dry years. A slight trend of increasing values in the 1980's followed by decreases in the 1990's and increases since 2005 was suggested by the LOWESS trend line. However, temporal linear regression analysis was not statistically significant (Table 18).

Figure 83. Long term trend in Chloride (Fairfax County Lab Data). Station 9. River mainstem.



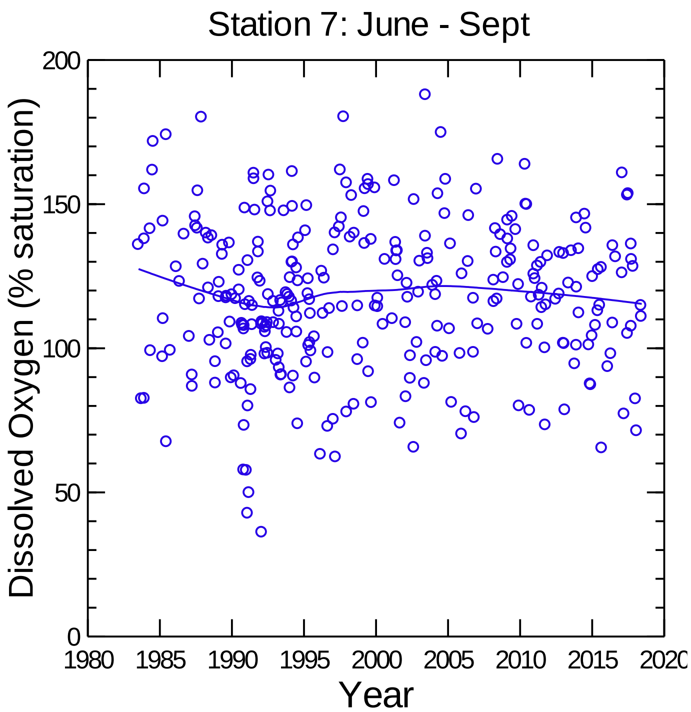
Dissolved oxygen in the cove has generally been in the range 7-13 mg/L during the summer months (Figure 84). A slight downward trend was observed through 1990, but since then the trend line has flattened, suggesting little consistent change and a mean of about 10 mg/L. In the cove dissolved oxygen (mg/L) did not exhibit a significant linear trend over the long term study period (Table 17).

Figure 84. Long term trend in Dissolved Oxygen, mg/L (GMU Data). Station 7. Gunston Cove.



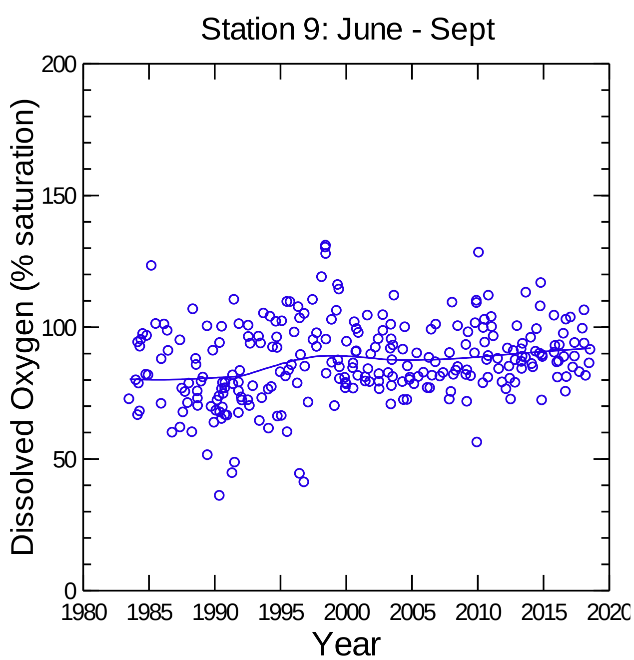
In the river dissolved oxygen values generally were in the range 5-9 mg/L over the long term study period (Figure 85). The LOWESS trend line some subtle changes from year to year, but little consistent pattern. The linear regression analysis over the entire period indicated a significant positive trend with slope of 0.026 mg/L per year or 0.9 mg/L over the period of record (Table 17).

Figure 85. Long term trend in Dissolved Oxygen, mg/L (GMU Data). Station 9. River mainstem.



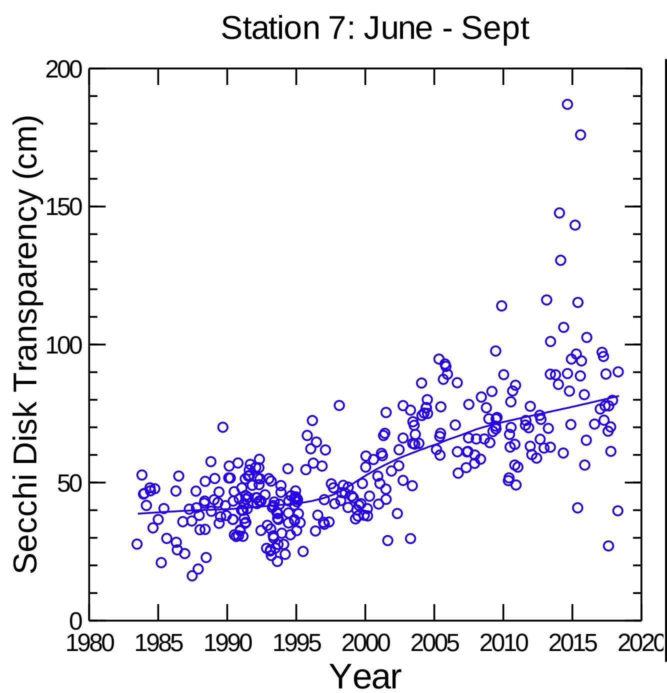
Dissolved oxygen was generally in the range 100-150% saturation in the cove over the long term study period indicating the importance of photosynthesis in the cove (Figure 86). A decline was indicated by the trend line through 1990 followed by a slight recovery in subsequent years. Percent saturation DO did not exhibit a significant linear trend over the long term study period (Table 17). 2018 values fell around the trend line.

Figure 86. Long term trend in Dissolved Oxygen, % saturation (GMU Data). Station 7. Gunston Cove.



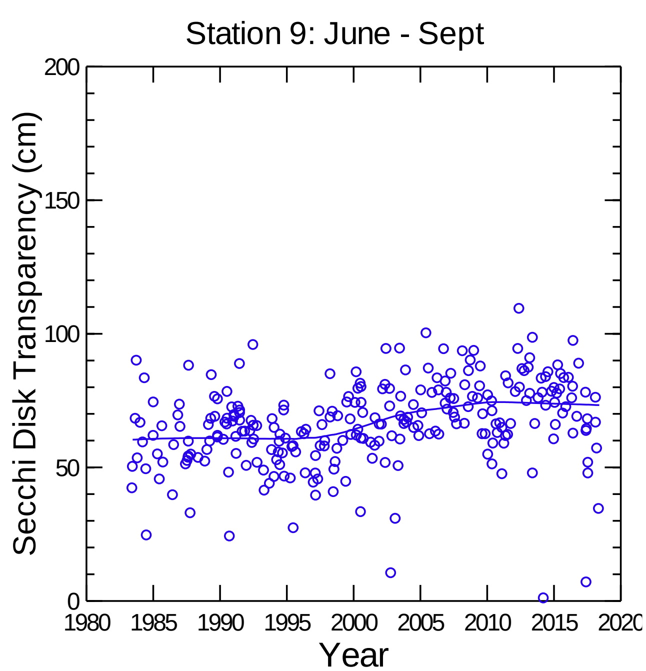
In the river dissolved oxygen was generally less than 100% indicating that photosynthesis was much less important in the river than in the cove and that respiration dominated (Figure 87). The trend line showed a very gradual increase which was statistically significant as indicated by regression analysis with a slope of 0.36% per year or about 13% over the course of the study (Table 17). 2018 readings were near the long term trend line. Despite this increase river DO was still below cove DO in general.

Figure 87. Long term trend in Dissolved Oxygen, % saturation (GMU Data). Station 9. Gunston Cove.



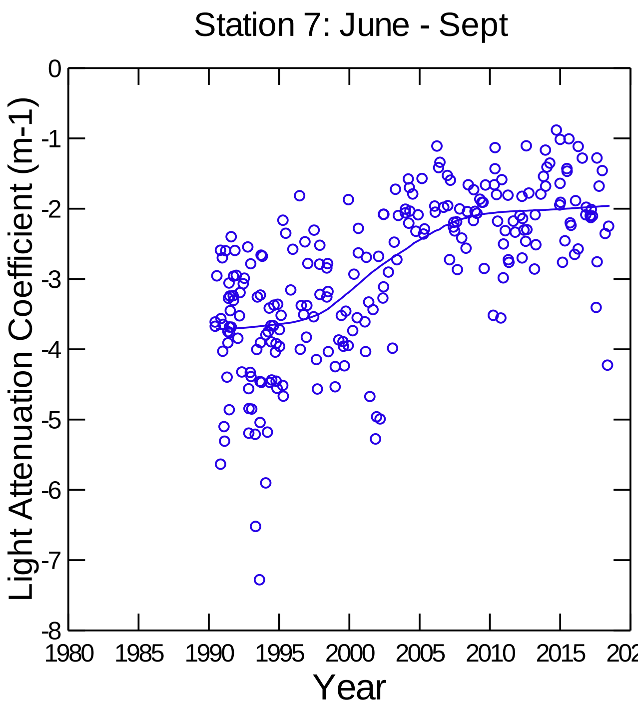
Secchi disk transparency is a measure of water clarity. Secchi disk was fairly constant from 1984 through 1995 with the trend line at about 40 cm (Figure 88). Since 1995 there has been a steady increase in the trend line from 40 cm to 85 cm in 2016. Linear regression was highly significant with a predicted increase of 1.7 cm per year or a total of nearly 60 cm over the study period (Table 17). From 2014-2017 most readings were above the trend line, but this was not true in 2018.

Figure 88. Long term trend in Secchi Disk Transparency (GMU Data). Station 7. Gunston Cove.



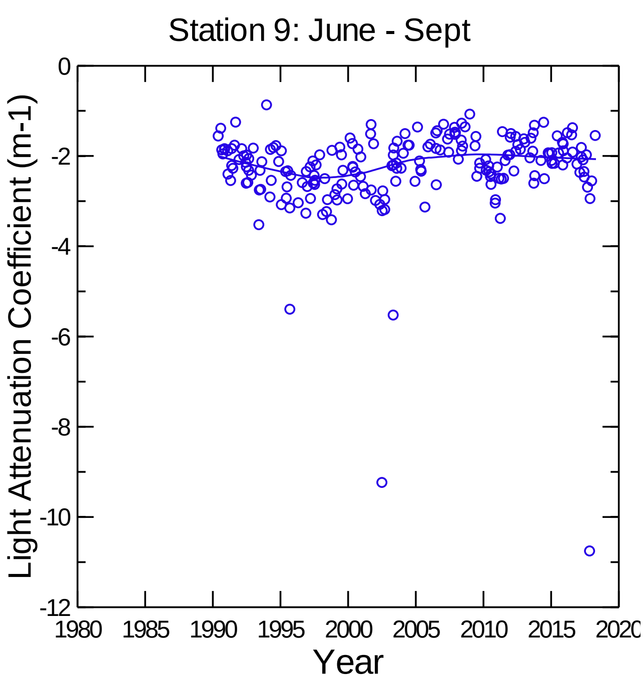
In the river Secchi depth was somewhat greater than in the cove in the 1980's (Figure 89). The trend line was fairly constant at about 60 cm until about 2000. A rise to about 75 cm was observed by 2005 where it has remained. Linear regression revealed a significant increase of 0.5 cm per year with total increase of 18 cm predicted over of the study period (Table 17). Many values in 2018 were below the trend line.

Figure 89. Long term trend in Secchi Disk Transparency (GMU Data). Station 9. River mainstem.



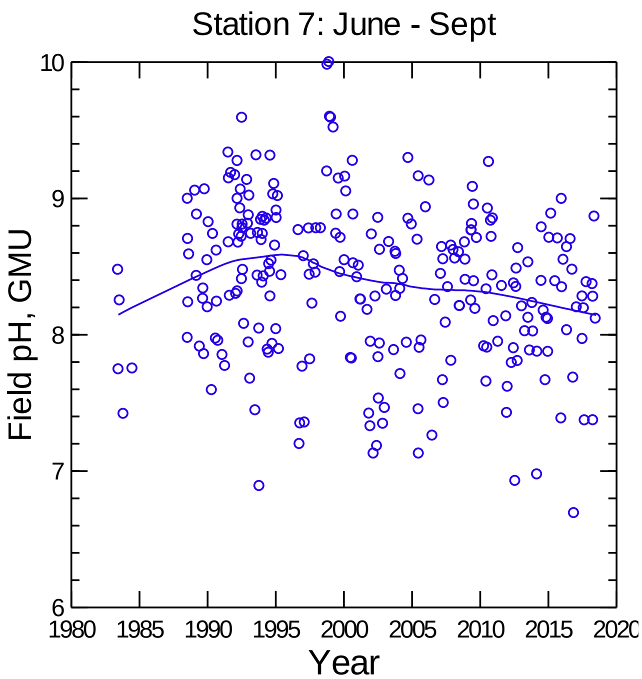
Light attenuation coefficient, another measure of water clarity, reinforces the conclusion that water clarity has been improving in the cove since 1995 (Figure 90). Trend line for the coefficient rose from about -4 to -2 m^{-1} during this time. Values in 2018 were generally below -2 for the first time in several years. Regression analysis revealed a significant linear increase in light attenuation coefficient over the period 1991-2018 with a slope of 0.09 per year yielding a prediction that light attenuation improved by about 2.4 units over this period (Table 17).

Figure 90. Long term trend in Light Attenuation Coefficient (GMU Data). Station 7. Gunston Cove.



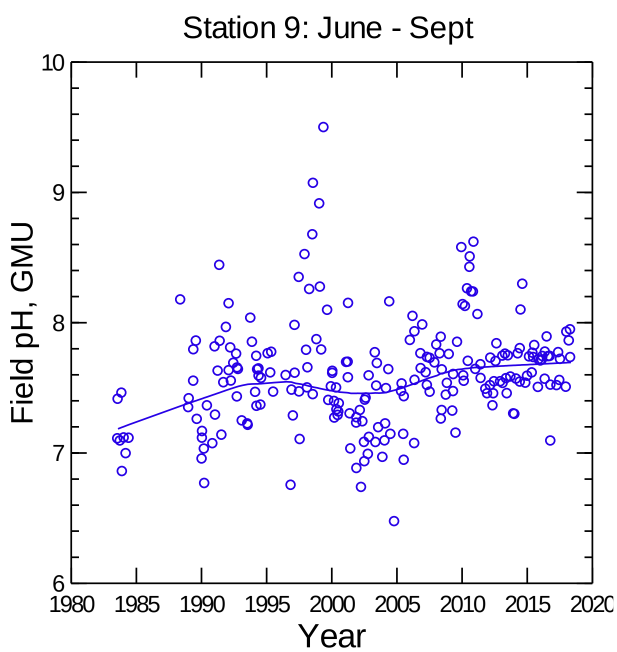
In the river light attenuation coefficient suggested a decline in light transparency between 1991 and 1997 followed by an increase through about 2008 (Figure 91). Between 2008 and 2016 the trend line indicates that light transparency has held fairly constant. Regression did not produce a significant slope over the period (Table 17).

Figure 91. Long term trend in Light Attenuation Coefficient (GMU Data). Station 9. River mainstem.



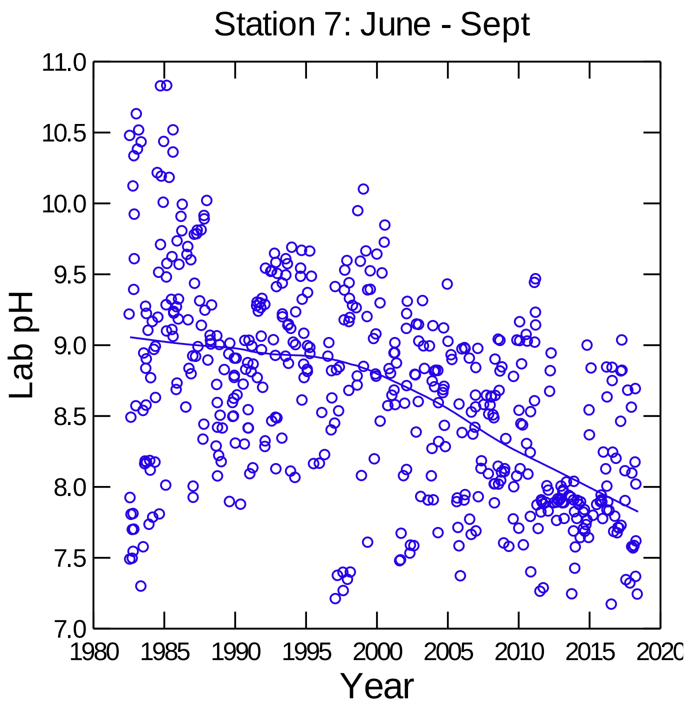
Field pH has not been measured as consistently over the entire study period as other parameters. Cove values have generally been in the 8-9 range. There is a clear trend of decreasing values since 1995 (Figure 92). Linear regression analysis now gives some evidence of a declining linear trend with a slope of -0.012 units per year when the entire study period was considered (Table 17).

Figure 92. Long term trend in Field pH (GMU Data). Station 7. Gunston Cove.



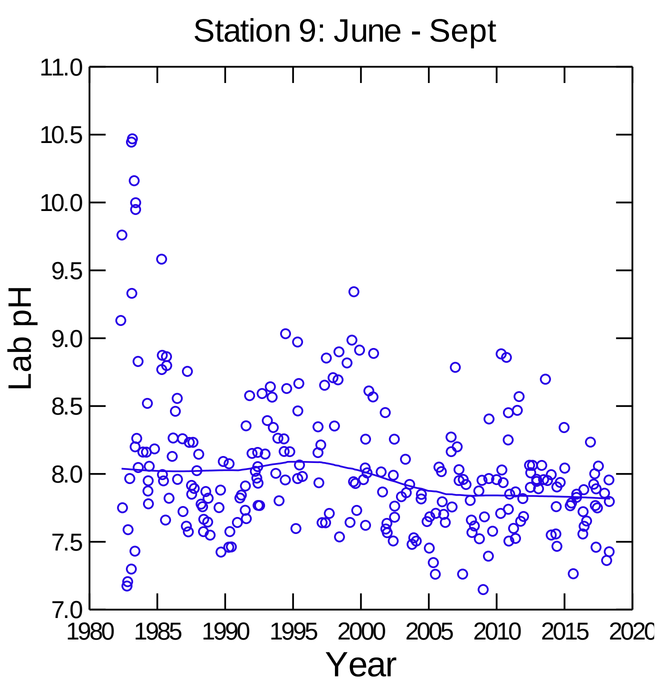
In the river a different pattern has been observed over this period (Figure 93). pH in the river has been consistently lower by about 1 pH unit than in the cove. If anything, the trend line has shown a tendency to increase. When all years were considered, field pH in the river shows a significant increase at a rate of 0.01 units per year (Table 17).

Figure 93. Long term trend in Field pH (GMU Data). Station 9. River mainstem.



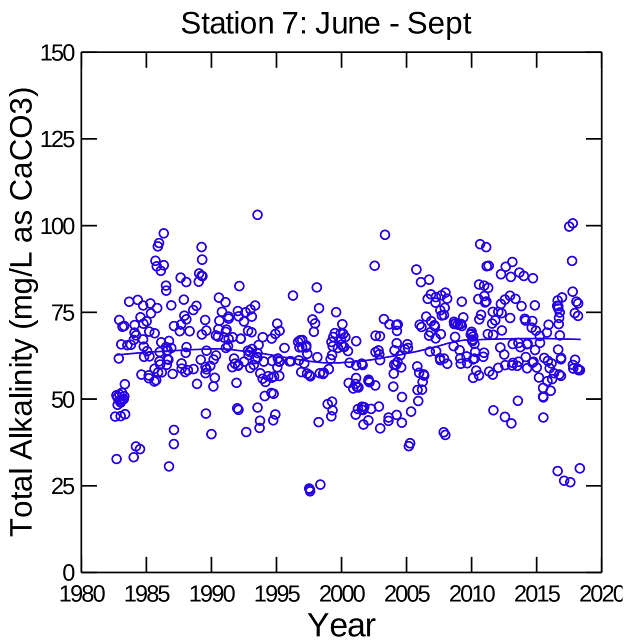
Lab pH as measured by Fairfax County personnel was generally in the range 8 to 10 over most of the long-term study period (Figure 94). Since about 1997 a decline is very evident with the trend line decreasing from about 9.1 to about 7.8. Linear regression indicates a significant decline in lab pH over the study period at a rate of about 0.034 pH units per year or a total of 1.2 units over the study period (Table 18). 2018 were generally below the trend line.

Figure 94. Long term trend in Lab pH (Fairfax County Lab Data). Station 7. Gunston Cove.



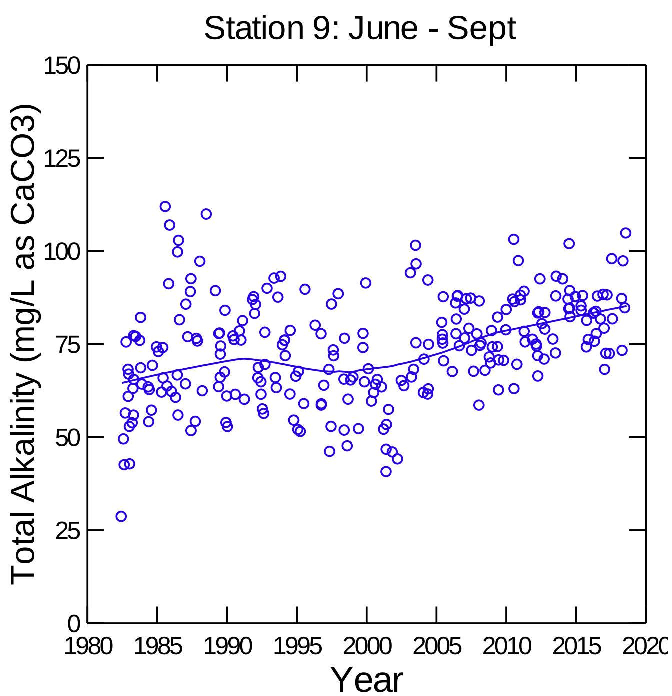
In the river, long term pH trends as measured by Fairfax County lab personnel indicate that most values fell between 7 and 8.5 (Figure 95). The trend line has increased and decreased slightly over the years. pH in the river showed a significant linear decline with a rate of 0.016 per year yielding a total decline of 0.56 units over the long-term study period (Table 18).

Figure 95. Long term trend in Lab pH (Fairfax County Lab Data). Station 9. Potomac mainstem.



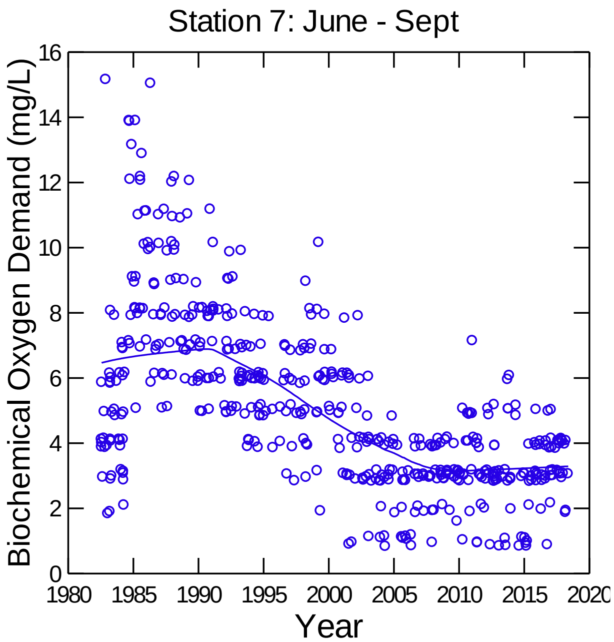
Total alkalinity as measured by Fairfax County personnel exhibited little variation early on and a slow increase since 2000 (Figure 96). The trend line at 2017 was slightly higher than it was in 1983. Overall, a very weak statistically significant linear trend has developed in total alkalinity in the cove over this period with a slope of 0.18 mg/L per year yielding a projected increase of about 6.3 mg/L over the entire study period (Table 18).

Figure 96. Long term trend in Total Alkalinity (Fairfax County Lab Data). Station 7. Gunston Cove.



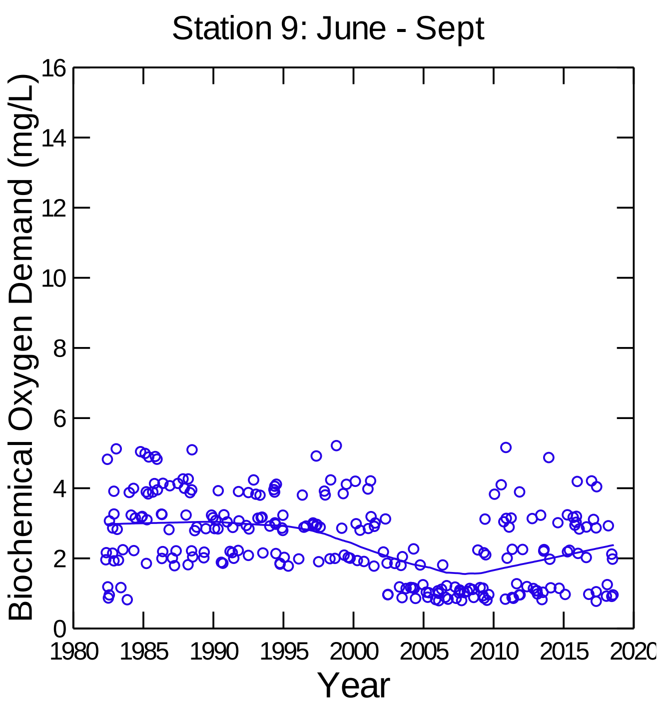
In the river a similar pattern has been observed over the three decades with an even clearer recent increase (Figure 97). There is a significant linear trend over the period with a slope of 0.43 mg/L suggesting a modest increase of about 15 mg/L over the entire study period (Table 18).

Figure 97. Long term trend in Total Alkalinity (Fairfax County Lab Data). Station 9. Potomac mainstem.



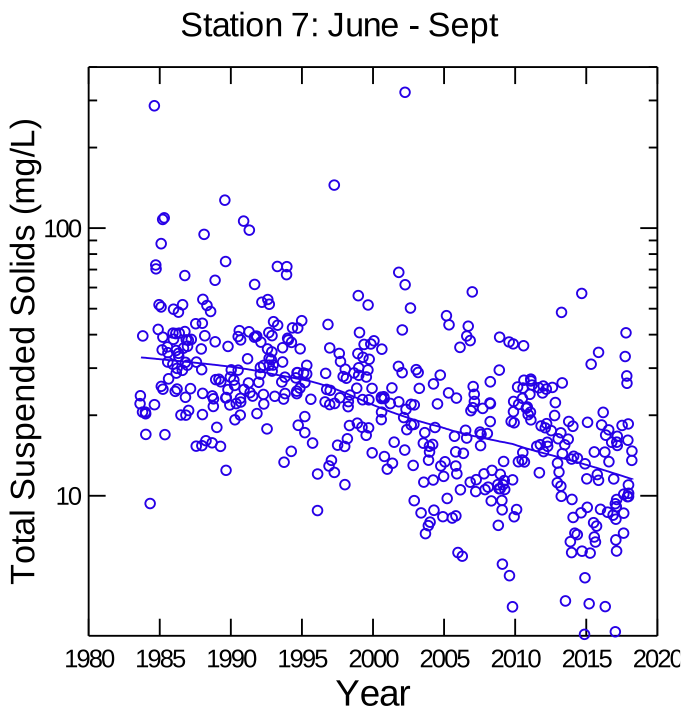
Biochemical oxygen demand has shown a distinct pattern over the long-term study period in Gunston Cove (Figure 98). In the 1980's the trend line rose from about 6 mg/L to 7 mg/L by 1989. Since then there has been a steady decline such that the trend line has dropped back to about 3 mg/L. BOD has shown a significant linear decline over the entire study period at a rate of 0.16 mg/L per year yielding a net decline of about 5.4 mg/L over the entire period of record (Table 18). It is difficult to tell if the decline is continuing as many readings are now below the detection limit.

Figure 98. Long term trend in Biochemical Oxygen Demand (Fairfax County Lab Data). Station 7. Gunston Cove.



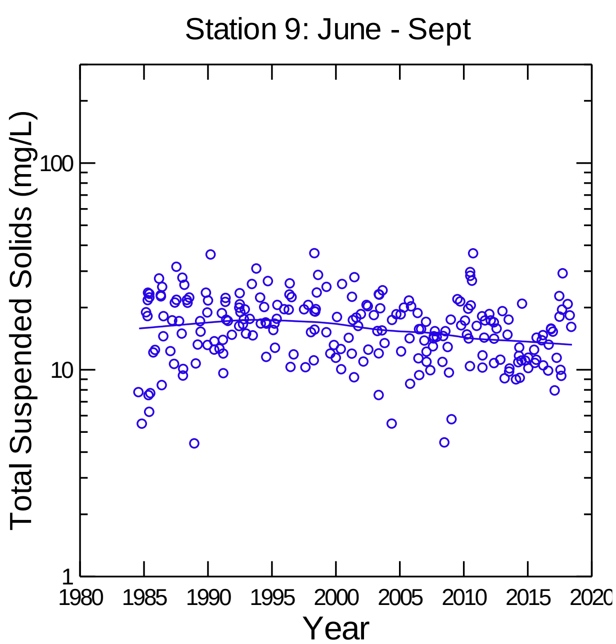
In the river biochemical oxygen demand exhibited a less distinct pattern through the mid 1990's (Figure 99). However, since that time it has decreased somewhat to a trend line value of about 1.0 mg/L. BOD in the river has exhibited a significant linear decrease at a rate of 0.046 units when the entire period of record was considered (Table 18). This would project to an overall decrease of 1.5 units. Many values now are non-detects of less than 2 mg/L making trends difficulty to examine.

Figure 99. Long term trend in Biochemical Oxygen Demand (Fairfax County Lab Data). Station 9. Potomac mainstem.



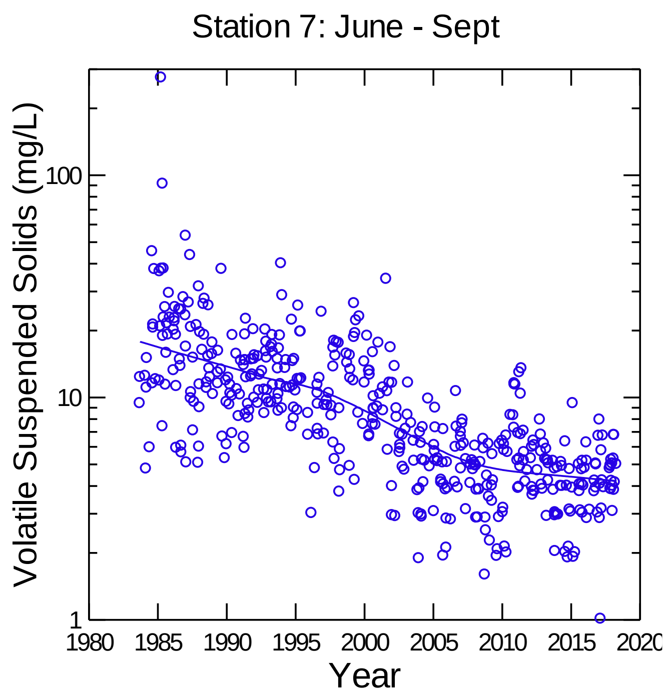
Total suspended solids (TSS) has shown a great deal of variability over the long-term study period. Nonetheless, a decreasing trend in TSS is clear in the cove with the trend line decreasing from about 32 mg/L in 1983 to about 12 mg/L in 2017 (Figure 100). Linear regression was significant indicating a decline of 0.89 mg/L per year yielding a total decline of 31 mg/L since 1984 (Table 18). However, several readings in 2018 were above the trend line.

Figure 100. Long term trend in Total Suspended Solids (Fairfax County Lab Data). Station 7. Gunston Cove.



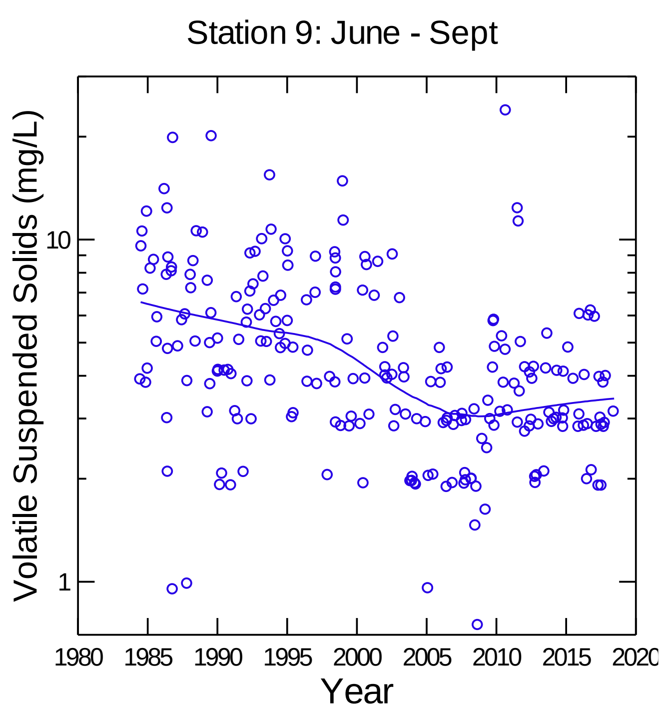
In the river TSS trends have not been as apparent (Figure 101). While much higher values have been observed sporadically, the LOWESS line remained steady at about 18-20 mg/L through most of the period with a slight decrease to about 15 mg/L suggested recently. In the river TSS exhibited a significant linear decline over the period of record at a rate of about 0.11 units per year yielding a total decline of about 3.8 mg/L over the entire study period (Table 18). Most readings in 2018 were above the long-term trend line.

Figure 101. Long term trend in Total Suspended Solids (Fairfax County Lab Data). Station 9. Potomac mainstem.



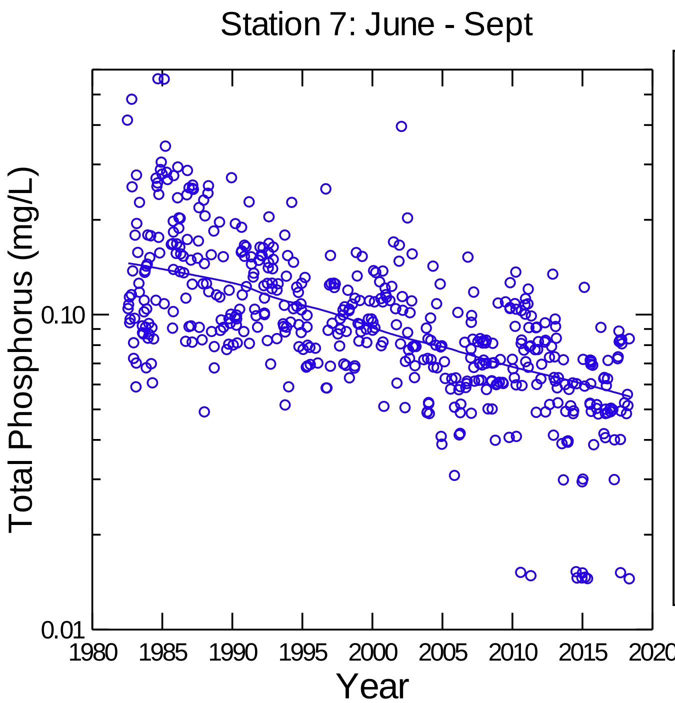
Volatile suspended solids have consistently declined over the study period in the cove (Figure 102). The LOWESS trend line has declined from 20 mg/L in 1984 to about 4 mg/L in 2018. VSS has demonstrated a significant linear decline at a rate of 0.58 mg/L per year or a total of 20 mg/L over the study period (Table 18).

Figure 102. Long term trend in Volatile Suspended Solids (Fairfax County Lab Data). Station 7. Gunston Cove.



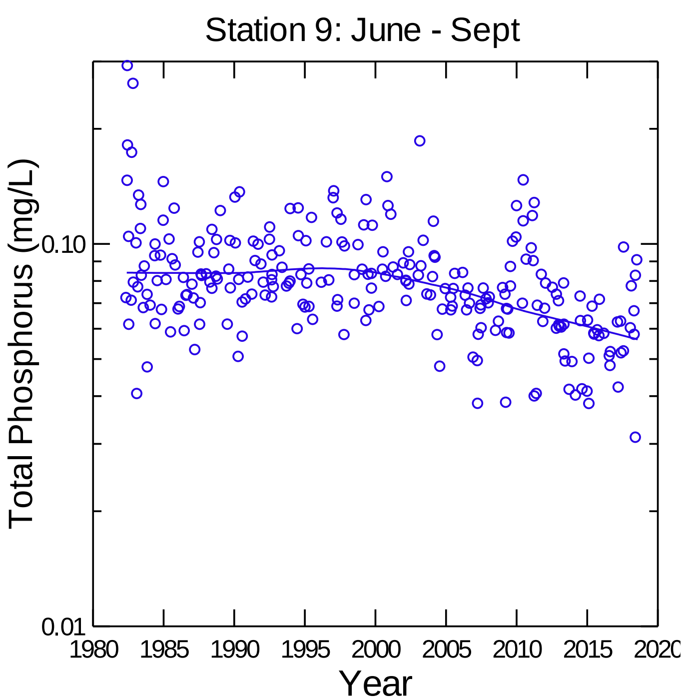
In the river the trend line for volatile suspended solids (VSS) was steady from 1984 through the mid 1990's, but decreased from 1995 to 2005. Trend line values of about 7 mg/L in 1984 dropped to about 3.5 mg/L by 2018 (Figure 103). VSS in the river demonstrated a significant linear decline at a rate of 0.12 mg/L per year or 4.2 mg/L since 1984 (Table 18).

Figure 103. Long term trend in Volatile Suspended Solids (Fairfax County Lab Data). Station 9. Potomac mainstem.



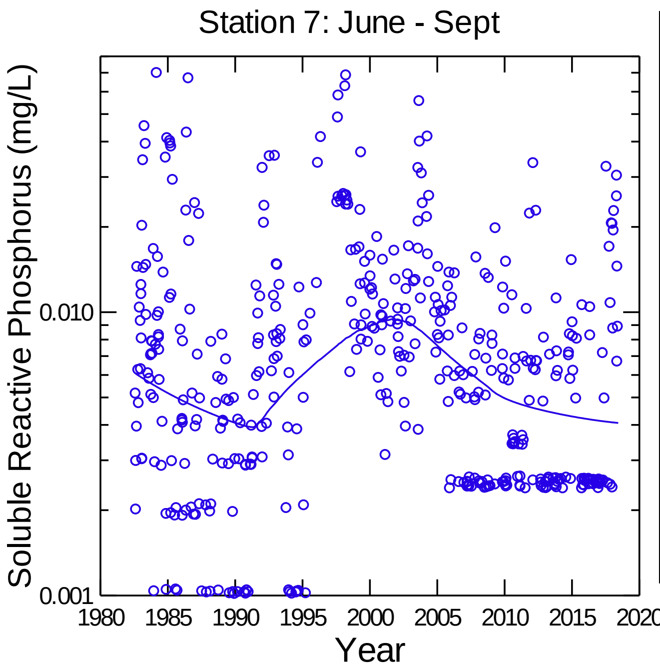
In the cove, total phosphorus (TP) has undergone a consistent steady decline since the late 1980's (Figure 104). By 2018 the trend line had dropped to 0.055 mg/L, more than half of the starting level. Linear regression over the entire period of record indicated a significant linear decline of -0.004 mg/L per year or 0.14 mg/L over the entire study period (Table 18).

Figure 104. Long term trend in Total Phosphorus (Fairfax County Lab Data). Station 7. Gunston Cove.



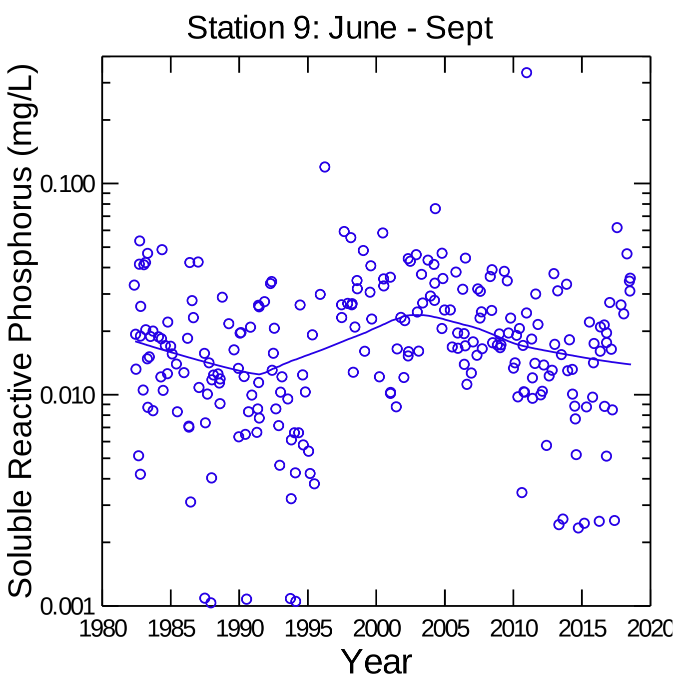
Total phosphorus (TP) values in the river have shown less of a trend over time (Figure 105). Values were steady through about 2000, then declined somewhat. TP exhibited a slight, but significant linear decrease in the river over the long-term study period with a very modest slope of -0.001 mg/L per year (Table 18).

Figure 105. Long term trend in Total Phosphorus (Fairfax County Lab Data). Station 9. Potomac mainstem.



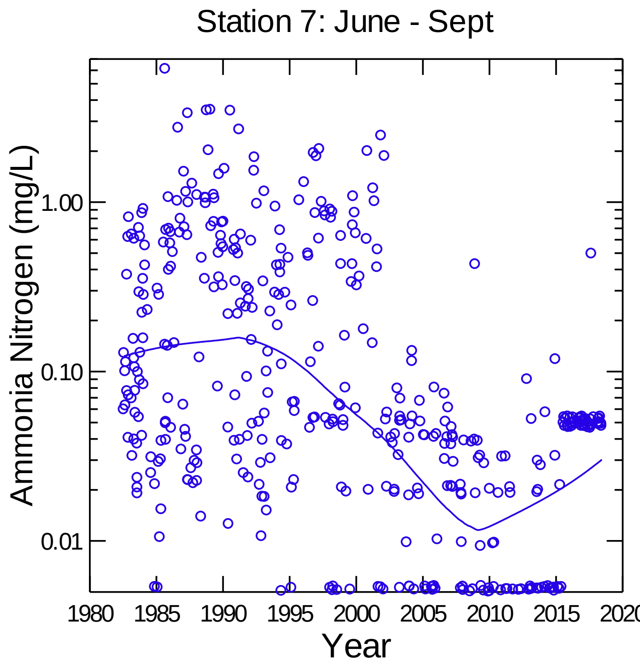
Soluble reactive phosphorus (SRP) declined in the cove during the first few years of the long-term data set, but demonstrated an increase to near its initial level by 2000 (Figure 106). Since then a decline has ensued. (Table 18). One possibility is that less SRP is entering the cove water; another is that increased SAV is taking more up. Note also that the detection limit has changed and that many readings are at the detection limit making trend analysis difficult and uncertain.

Figure 106. Long term trend in Soluble Reactive Phosphorus (Fairfax County Lab Data). Station 7. Gunston Cove.



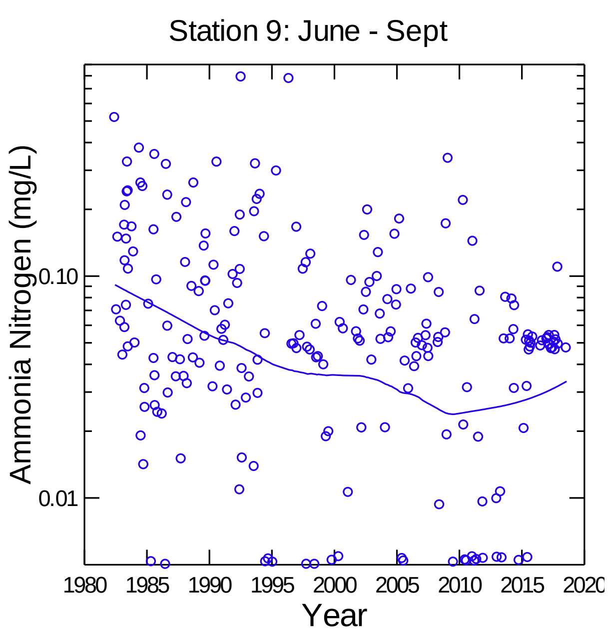
Soluble reactive phosphorus (SRP) in the river has generally been present at higher levels than in the cove, but has undergone a similar decline-resurgence-decline (Figure 107). Linear regression was not significant (Table 18). There were a significant number of non-detect values, but fewer than in the cove.

Figure 107. Long term trend in Soluble Reactive Phosphorus (Fairfax County Lab Data). Station 9. Potomac mainstem.



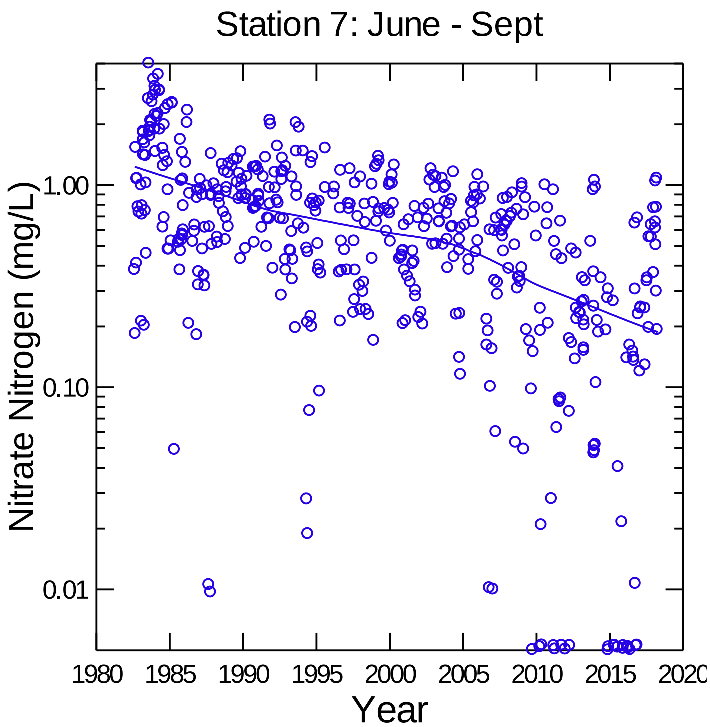
Ammonia nitrogen levels were very variable over the long term study period in the cove, but a trend of decreasing values is evident from the LOWESS trend line (Figure 108). Since 1989 the trend line has decreased from about 0.2 mg/L to about 0.02 mg/L. Linear regression has revealed a significant decline over the entire period of record with a rate of 0.016 mg/L per year yielding a total decline of 0.58 mg/L (Table 18). Note the increase in values below the detection limit over time (clustered at bottom of graph) and the increase in the detection limit. This is making the detection of trends increasingly uncertain.

Figure 108. Long term trend in Ammonia Nitrogen (Fairfax County Lab Data). Station 7. Gunston Cove.



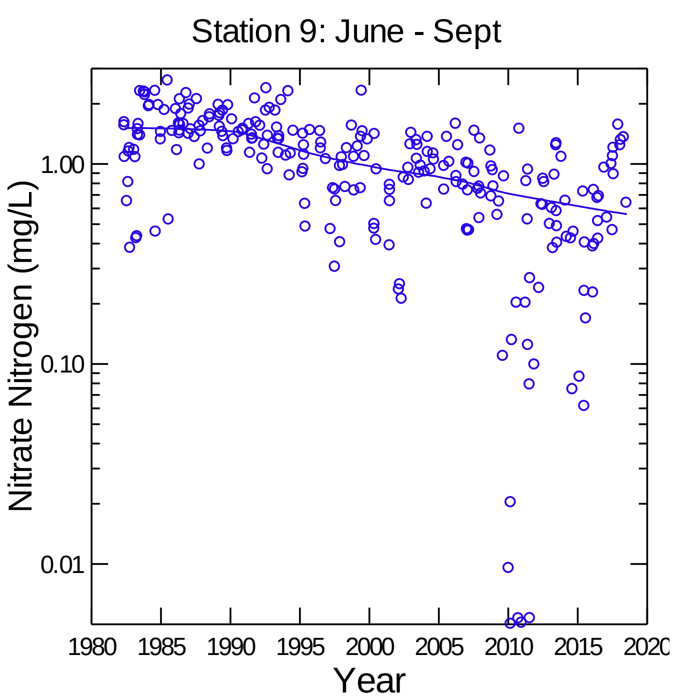
In the river a decreasing trend in ammonia nitrogen has also been observed over most of the study period (Figure 109). Between 1983 and 1999 the trend line dropped from 0.1 mg/L to 0.04 mg/L. Since 1999 it has continued to decline and is now at about 0.02 mg/L. Overall, in the river ammonia nitrogen has demonstrated a significant decline over the study period at a rate of 0.003 mg/L per year or a total of 0.09 over the study period (Table 18). Again, the number of non-detects is increasing.

Figure 109. Long term trend in Ammonia Nitrogen (Fairfax County Lab Data). Station 9. Potomac mainstem.



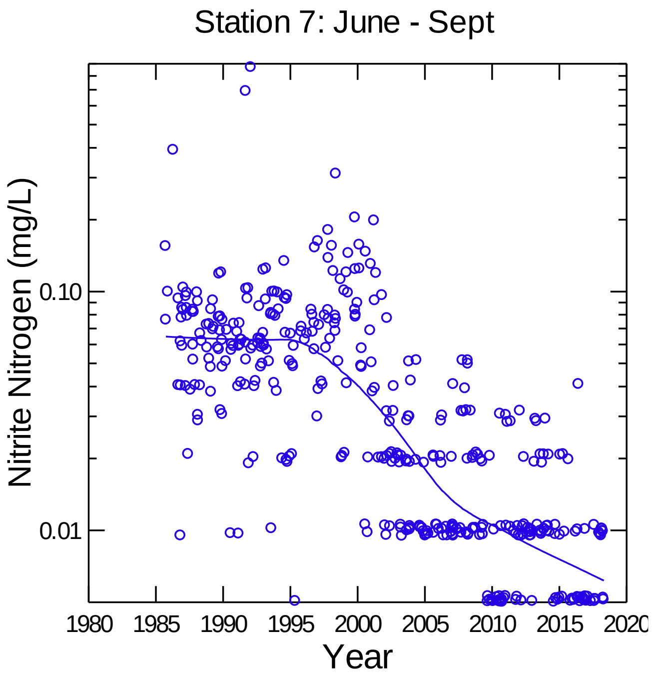
Nitrate nitrogen has demonstrated a steady decline in the cove over the entire period of record (Figure 110). The trend line was at about 1 mg/L in 1983 and by 2018 was below 0.2 mg/L. Linear regression suggested a decline rate of 0.032 mg/L per year yielding a total decline of 1.1 mg/L over the long-term study period (Table 18). Note the large number of non-detect values in recent years. Values in 2018 were consistently above the trend line.

Figure 110. Long term trend in Nitrate Nitrogen (Fairfax County Lab Data). Station 7. Gunston Cove.



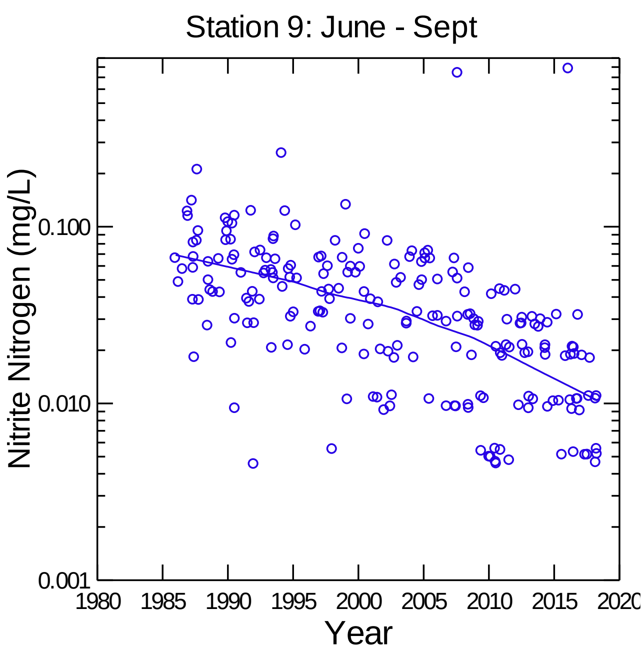
In the river nitrate nitrogen has declined steadily since about 1985 (Figure 111). The trend line dropped from 1.5 mg/L in the mid 1980's to 0.4 mg/L in 2017. Linear regression indicated a rate of decline of -0.032 mg/L per yr which would yielded a 1.1 mg/L decrease in nitrate nitrogen over the study period (Table 18). Values in 2018 were consistently above the trend line.

Figure 111. Long term trend in Nitrate Nitrogen (Fairfax County Lab Data). Station 9. River mainstem.



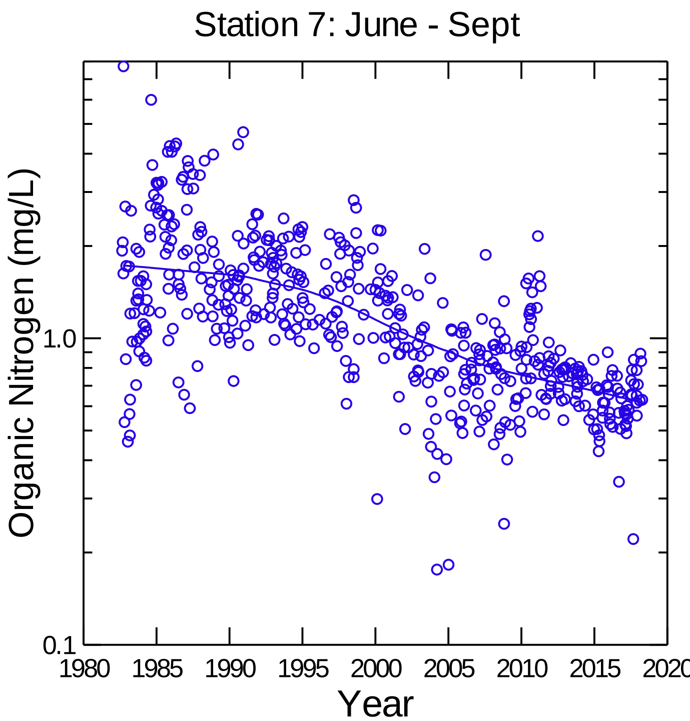
The trend line for nitrite nitrogen indicated steady values at about 0.06-0.07 mg/L through 1999 (Figure 112). Since then there is clear evidence for a decline with the LOWESS line dropping below 0.01 in 2018. Linear regression revealed a significant decline with a slope of 0.003 mg/L per year when the entire period of record was considered (Table 18). Most values in recent years have been at or below the detection limits.

Figure 112. Long term trend in Nitrite Nitrogen (Fairfax County Lab Data). Station 7. Gunston Cove.



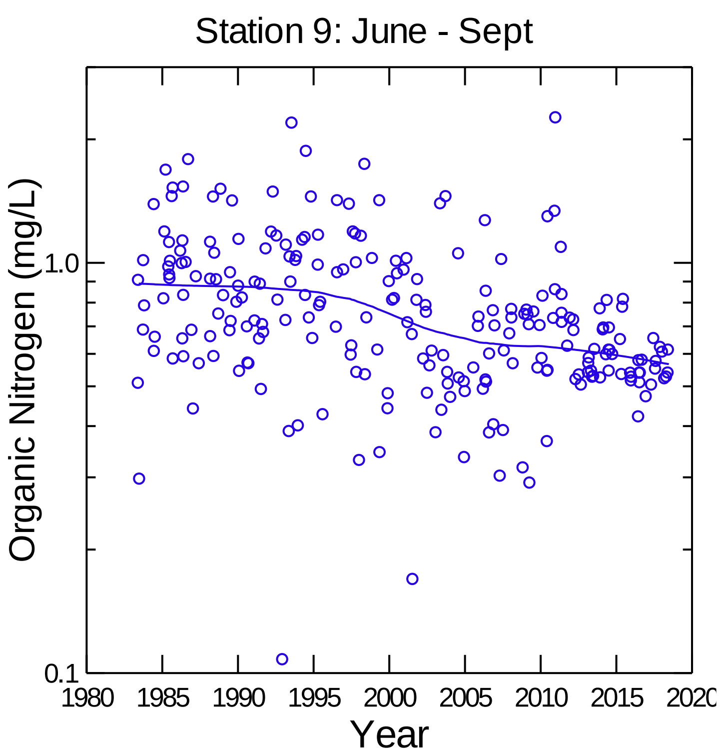
Nitrite nitrogen in the river demonstrated a pattern of decrease during the long term study period (Figure 113). The LOWESS line dropped from 0.07 mg/L in 1986 to less than 0.01 mg/L in 2018. Linear regression indicated a significant linear decline at a rate of 0.001 mg/L per year or 0.03 mg/L over the study period (Table 18).

Figure 113. Long term trend in Nitrite Nitrogen (Fairfax County Lab Data). Station 9. Potomac mainstem.



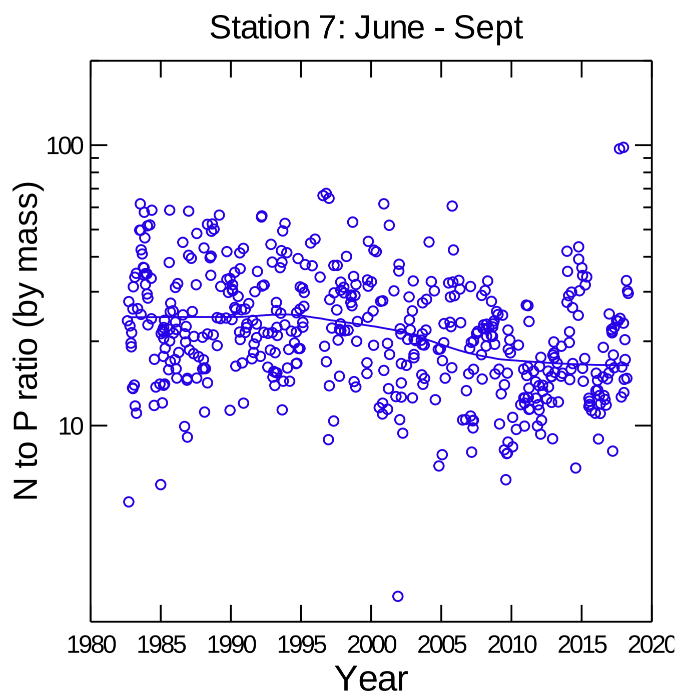
Organic nitrogen in the cove was fairly high in the 1980's and has since undergone a consistent decline through 2017 (Figure 114). In 1983 the trend line was at 1.5 mg/L and dropped below 0.7 mg/L by 2018. Regression analysis indicated a significant decline over the study period at a rate of about 0.047 mg/L per year or a total of 1.5 mg/L over the whole study period (Table 18).

Figure 114. Long term trend in Organic Nitrogen (Fairfax County Lab Data). Station 7. Gunston Cove.



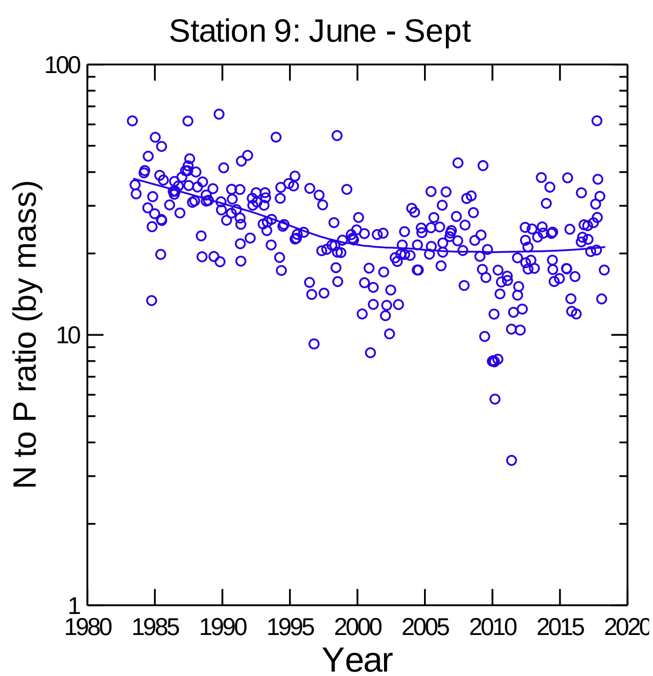
In the river organic nitrogen was steady from 1984 through 1995 and since then has shown perhaps a modest decline (Figure 115). The LOWESS line peaked at about 0.9 mg/L and has dropped to about 0.6 mg/L. Regression analysis indicated a significant linear decline at a rate of 0.01 mg/L when the entire period of record was considered for a total decline of 0.3 mg/L (Table 18).

Figure 115. Long term trend in Organic Nitrogen (Fairfax County Lab Data). Station 9. River mainstem.



Nitrogen to phosphorus ratio (N/P ratio) in the cove exhibited large variability, but the trend line was flat until about 1995. Since then, there has been a clear decline with the LOWESS line approaching 15 by 2018 (Figure 116). Regression analysis over the period of record indicates a statistically significant decline at a rate of 0.29 per year or about 10 units over the entire period (Table 18). This ratio is calculated using nitrate, TKN, and TP values and are less accurate when any of those are below detection limits.

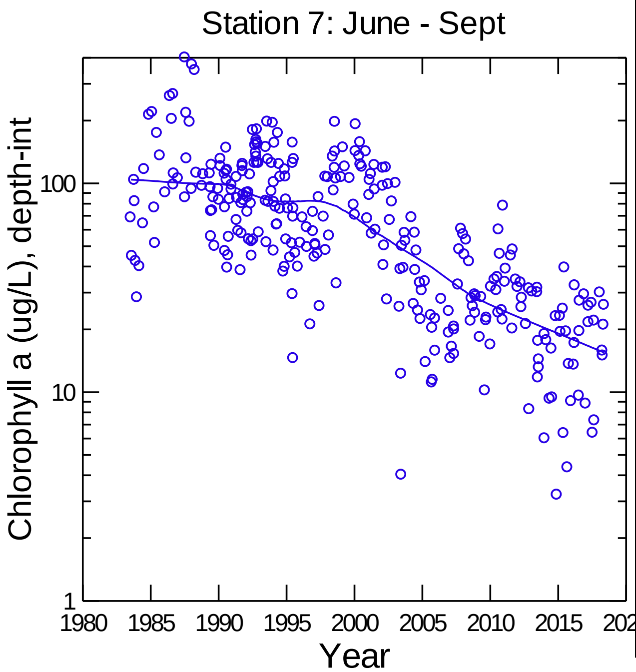
Figure 116. Long term trend in N to P Ratio (Fairfax County Lab Data). Station 7. Gunston Cove.



Nitrogen to phosphorus ratio in the river exhibited a strong continuous decline through about 2000 and has declined more slowly since then (Figure 117). The LOWESS trend line declined from about 35 in 1984 to 20 in 2018. Linear regression analysis confirmed this decline and suggested a rate of 0.45 units per year or a total of 16 units over the long term study period (Table 18).

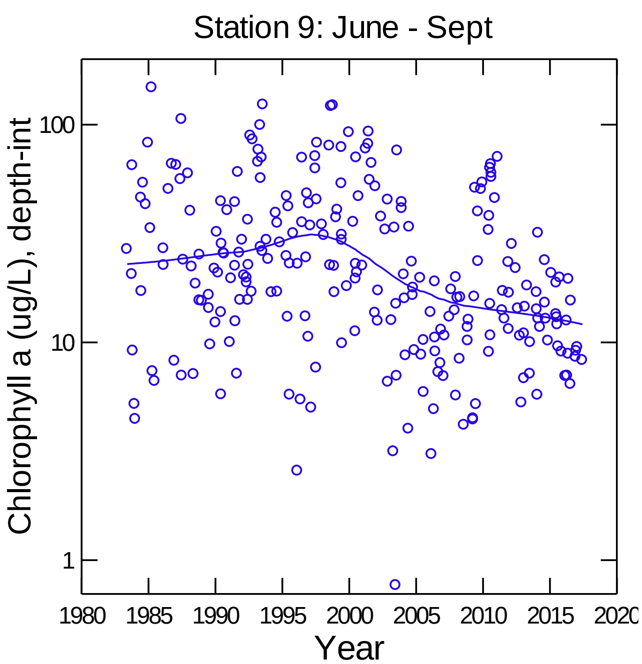
Figure 117. Long term trend in N to P Ratio (Fairfax County Lab Data). Station 9. River mainstem.

C. Phytoplankton Trends: 1984-2018



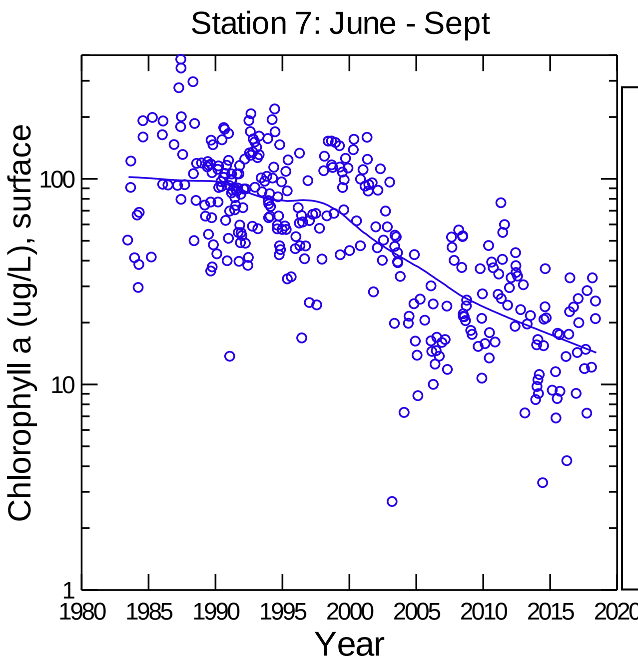
After increasing through much of the 1980's, depth-integrated chlorophyll *a* in the cove demonstrated a gradual decline from 1988 to 2000 and a much stronger decrease since then (Figure 118). The LOWESS line has declined from about 100 µg/L to less than 15 µg/L in 2017. The observed decrease has resulted in chlorophyll values within the range of water clarity criteria allowing SAV growth to 0.5 m and 1.0 m (43 µg/L and 11 µg/L, respectively) (CBP 2006). This would imply adequate light to support SAV growth over much of Gunston Cove. Regression analysis has revealed a clear linear trend of decreasing values at the rate of 3.74 µg/L per year or 130 µg/L over the 35-year long term data set (Table 17).

Figure 118. Long term trend in Depth-integrated Chlorophyll *a* (GMU Lab Data). Station 7. Gunston Cove.



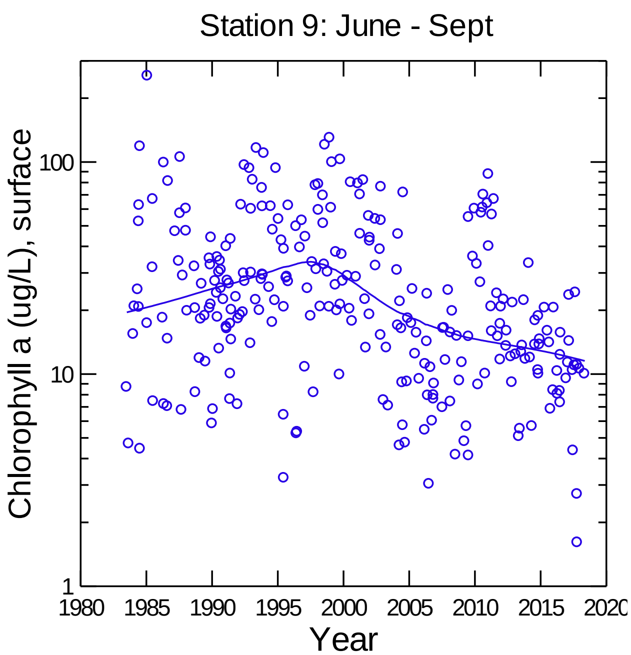
In the river depth-integrated chlorophyll *a* increased gradually through 2000 with the trend line rising from 20 to 30 µg/L (Figure 119). This was followed by a strong decline through about 2005 reaching about 18 µg/L with a further gradual decline to date. Regression analysis revealed a significant linear decline at a rate of 0.8 µg/L/yr when the entire period is considered (Table 17) yielding a total decline of about 28 ug/L.

Figure 119. Long term trend in Depth-integrated Chlorophyll *a* (GMU Lab Data). Station 9. River mainstem.



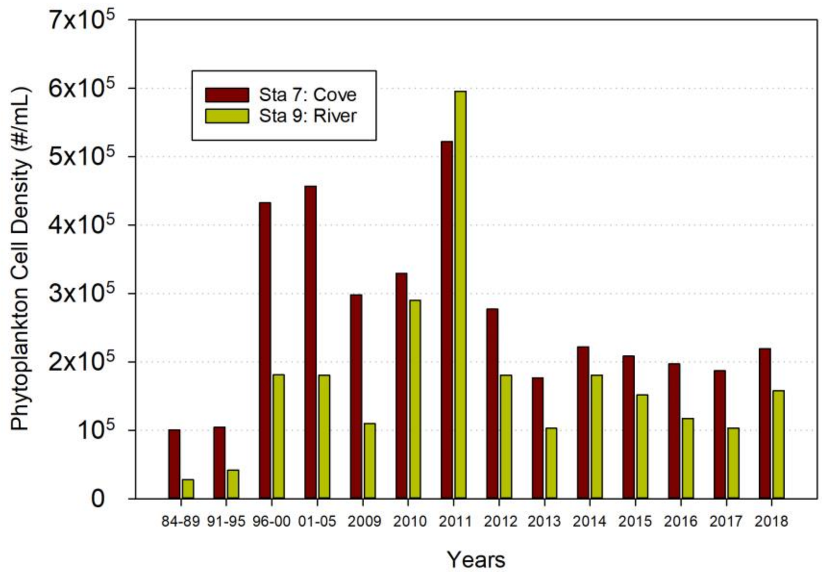
Surface chlorophyll *a* in the cove also exhibited a clear decline over the long term study period, especially since 2000 (Figure 120). Trend line values of about 100 µg/L in 1988 dropped to less than 15 µg/L in 2018. Linear regression confirmed the linear decline and suggested a rate of 3.8 µg/L per year or 130 µg/L over the entire study (Table 17).

Figure 120. Long term trend in Surface Chlorophyll *a* (GMU Data). Station 7. Gunston Cove.



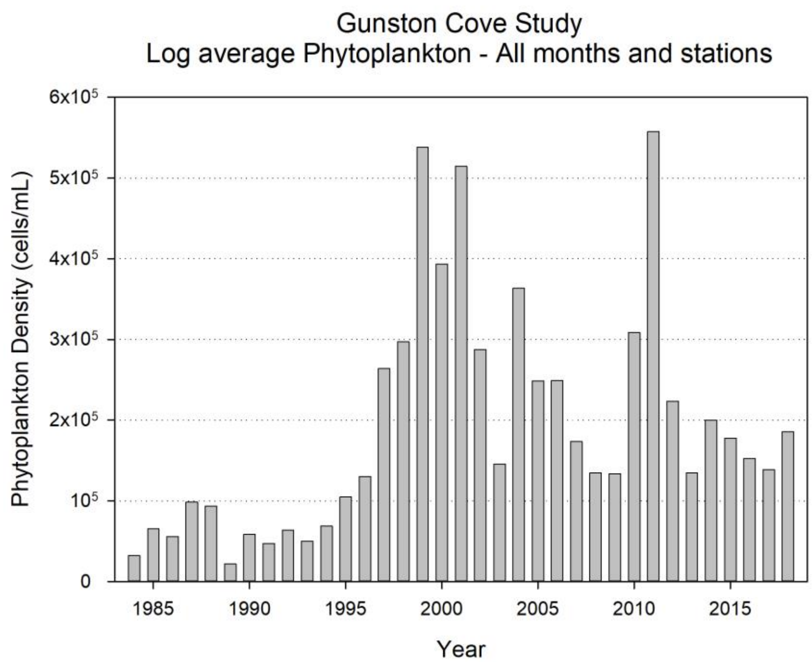
In the river the LOWESS line for surface chlorophyll *a* increased slowly from 1983 to 2000 and then declined markedly through 2005 (Figure 121). Values have stabilized since then at about 15 µg/L. Linear regression revealed a significant decline in surface chlorophyll across this period with a rate of 0.84 µg/L/yr or about 29 µg/L over the whole period (Table 17).

Figure 121. Long term trend in Surface Chlorophyll *a* (GMU Data). Station 9. River mainstem.



Phytoplankton cell density in both the cove and the river in 2018 was similar to values observed since 2012 (Figure 122). While cell density does not incorporate cell size, it does provide some measure of the abundance of phytoplankton and reflects the continuing decrease in phytoplankton in the study area which is expected with lower nutrient loading and should help improve water clarity.

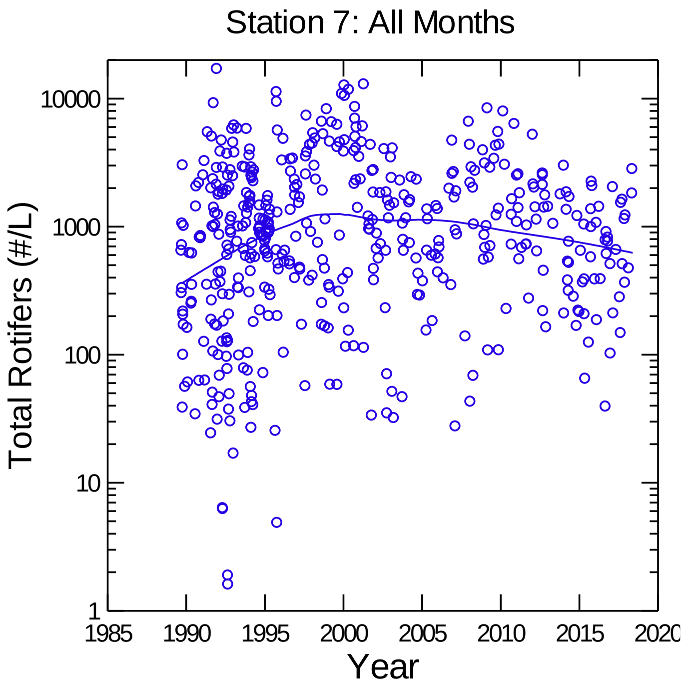
Figure 122. Interannual Comparison of Phytoplankton Density by Region.



By looking at individual years (Figure 123), we see that phytoplankton densities in 2018 remained lower than the high levels observed during the 1995 to 2005 period.

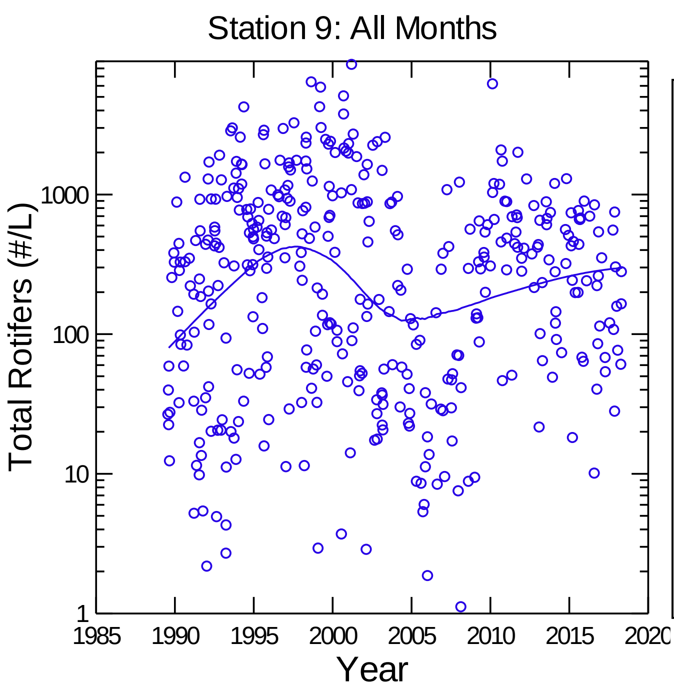
Figure 123. Interannual Trend in Average Phytoplankton Density.

D. Zooplankton Trends: 1990-2018



In the Cove total rotifers continued to exhibit a slow decline after an initial decade (1990-2000) of steady increase (Figure 124). The LOWESS fit line indicated about 600/L in 2013, up from about 400/L in 1990. Linear regression analysis continued to indicate a statistically significant linear increase in total rotifers over the period since 1990 (Table 18), but it is becoming more tenuous.

Figure 124. Long term trend in Total Rotifers. Station 7. Gunston Cove.



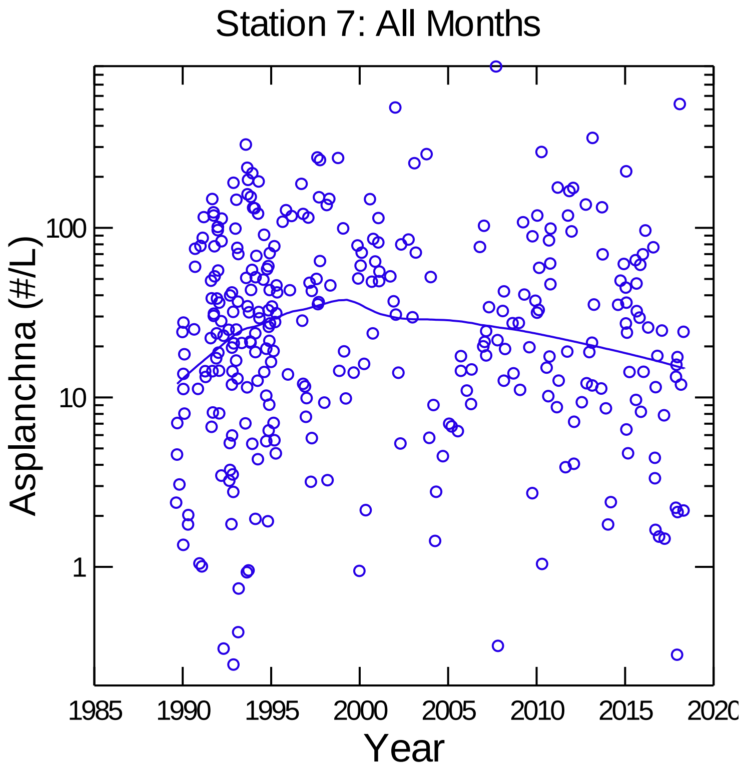
In the Potomac mainstem, rotifers exhibited an initial increase from 1990 to 1998, followed by a decline from 1999 to 2005 and more recently another increase (Figure 125). Trend line values in 1990 were about 80/L and now are about 300/L approaching 1998 values. However, when the entire 1990-2018 period was considered, total rotifers did not exhibit a significant linear trend in the river (Table 18).

Figure 125. Long term trend in Total Rotifers. Station 9. River mainstem.

Table 19
Correlation and Linear Regression Coefficients
Zooplankton Parameters vs. Year for 1990-2018
All Nonzero Values Used, All Values Logged to Base 10

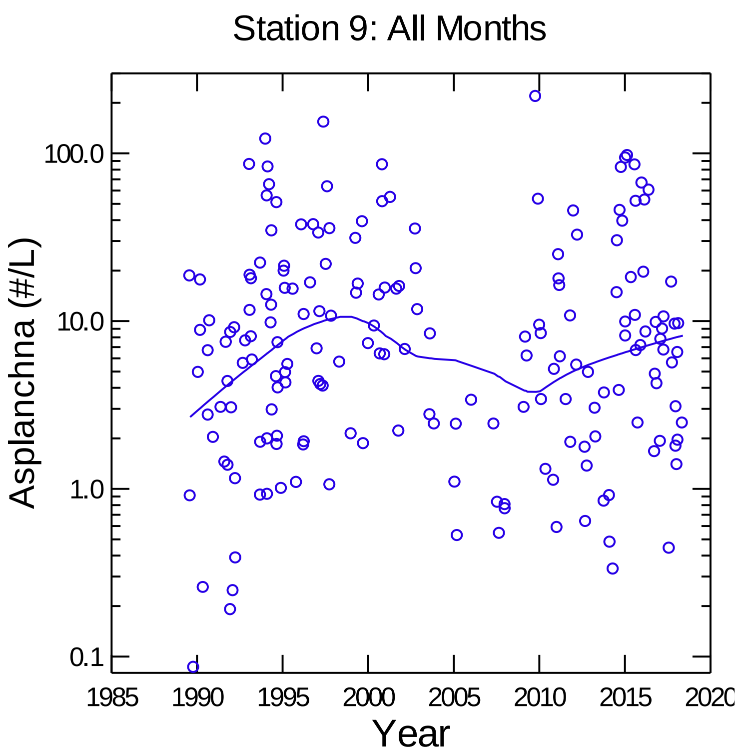
	Station 7 (N=588)			Station 9 (N=441)		
Parameter	Corr. Coeff.	Reg. Coeff.	Signif.	Corr. Coeff.	Reg. Coeff.	Signif.
Asplanchna (m)	0.015 (321)	---	---	0.031 (188)	---	---
Brachionus (m)	0.066 (448)	---	---	0.025 (371)	---	---
Conochilidae (m)	0.096 (391)	0.008	0.058	0.091 (310)	---	---
Filinia (m)	0.089 (390)	---	---	0.184 (270)	-0.015	0.002
Keratella (m)	0.296 (458)	0.026	<0.001	0.114 (384)	0.011	0.026
Polyarthra (m)	0.101 (430)	0.009	0.036	0.017 (353)	---	---
Total Rotifers (m)	0.108 (476)	0.008	0.019	0.015 (396)	---	---
Bosmina (m)	0.045 (275)	---	---	0.049 (328)	---	---
Diaphanosoma (M)	0.200 (376)	-0.030	<0.001	0.216 (280)	-0.027	<0.001
Daphnia (M)	0.047 (293)	---	---	0.105 (198)	-0.151	0.034
Chydorid cladocera (M)	0.096 (261)	---	---	0.006 (185)	---	---
Leptodora (M)	0.260 (219)	-0.029	<0.001	0.388 (161)	-0.038	<0.001
Copepod nauplii (m)	0.417 (455)	0.028	<0.001	0.208 (392)	0.017	<0.001
Calanoid copepods (M)	0.176 (541)	-0.020	<0.001	0.063 (415)	---	---
Cyclopoid copepods (M)	0.057 (503)	---	---	0.058 (401)	---	---
Adult and copepodid copepods (M)	0.087 (571)	-0.009	0.038	0.045 (436)	---	---

n values (# of non-zero data points) are shown in Corr. Coeff. column in parentheses. Number of total samples indicated in headings.
Significance column indicates the probability that a correlation coefficient this large could be due to chance alone. If this probability is greater than 0.05, then NS (not significant) is indicated. * = marginally significant. M indicates species was quantified from macrozooplankton samples; m indicates quantification from microzooplankton samples.



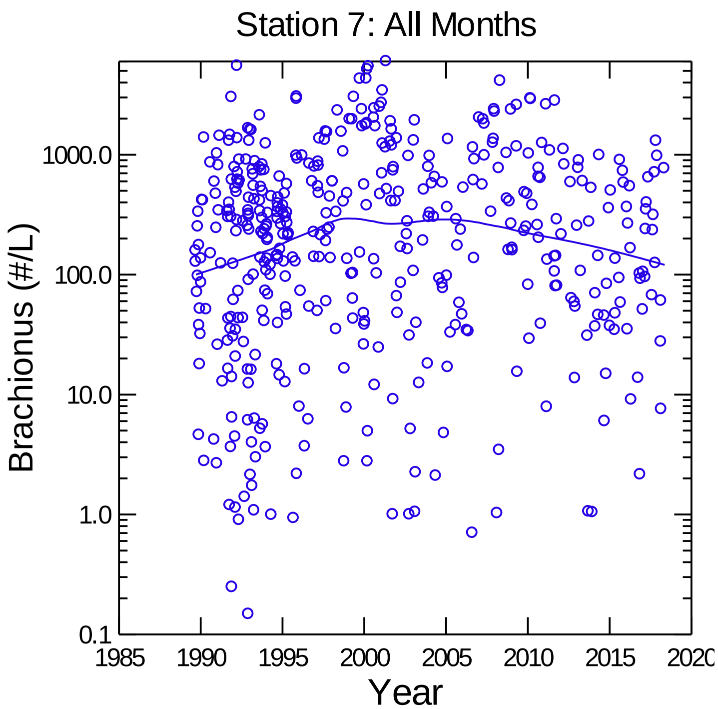
Asplanchna has shown a similar trend as total rotifers at a much lower abundance level (Figure 126). The LOWESS line increased in the 1990's, but has sinced decreased to near initial levels. No linear trend was found over the study period (Table 19).

Figure 126. Long term trend in *Asplanchna*. Station 7. Gunston Cove.



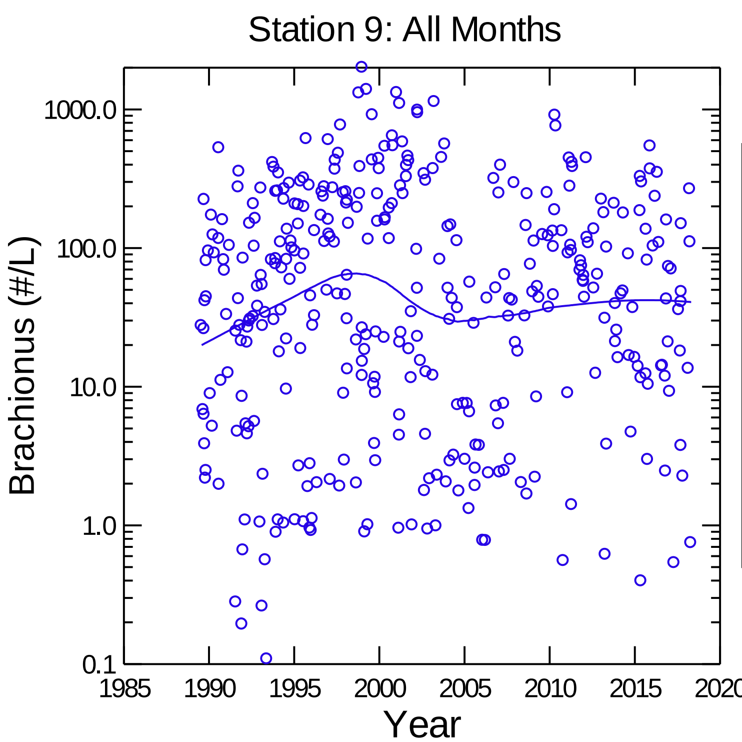
Asplanchna was found at lower densities in the river, but has displayed similar patterns (Figure 127). No linear trend was indicated when the entire study period was considered (Table 19).

Figure 127. Long term trend in *Asplanchna*. Station 9. River mainstem.



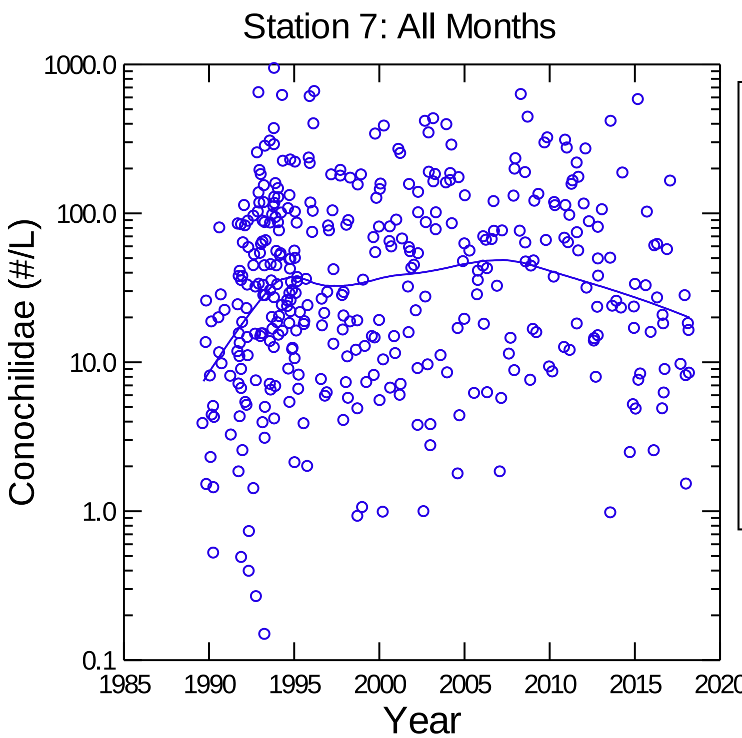
Brachionus is the dominant rotifer in Gunston Cove and the trends in total rotifers are generally mirrored in those in *Brachionus* (Figure 128). The LOWESS line for *Brachionus* suggested about 100/L in 2018, about what was found in 1990. No linear trend was found over the study period (Table 19).

Figure 128. Long term trend in *Brachionus*. Station 7. Gunston Cove.



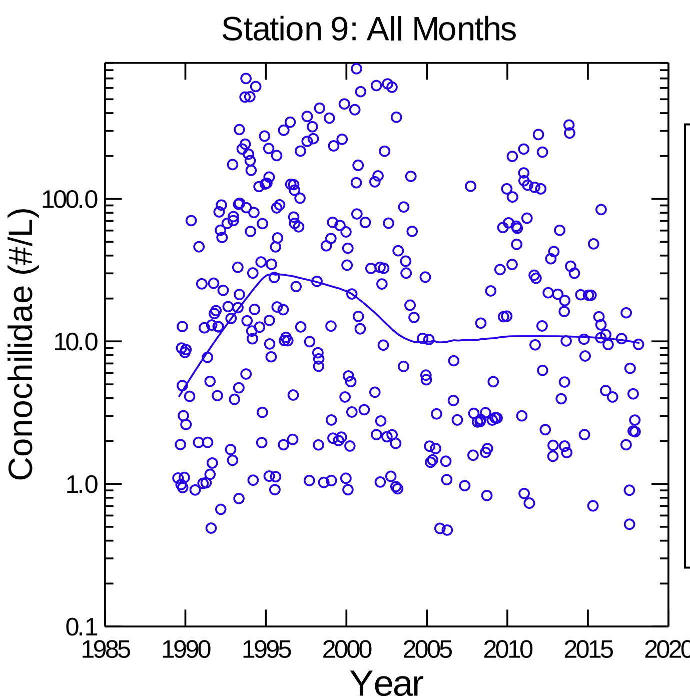
Brachionus was found at lower densities in the river. In the river the LOWESS line for *Brachionus* increased through 2000, but dropped markedly from 2000-2005. Since 2005 a slight increase has been noted (Figure 129). No linear trend was indicated when the entire study period was considered (Table 19).

Figure 129. Long term trend in *Brachionus*. Station 9. River mainstem.



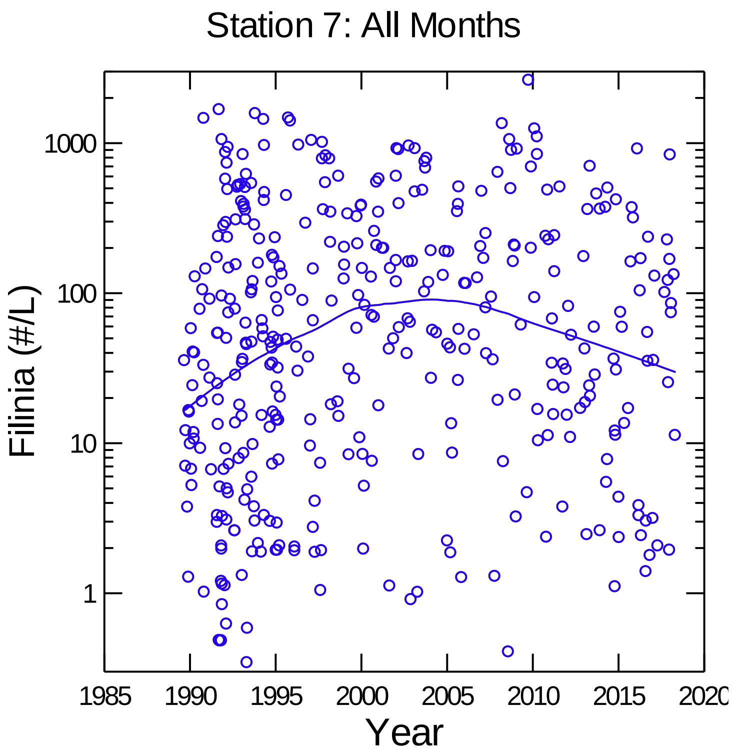
Conochilidae increased strongly from 1990-1995 and since then has leveled off. In 2018 the LOWESS trend line stood at about 20/L (Figure 130). This was well above levels of about 5/L in 1990. Over the entire period of record, a marginally significant linear increase was found (Table 19).

Figure 130. Long term trend in Conochilidae. Station 7. Gunston Cove.



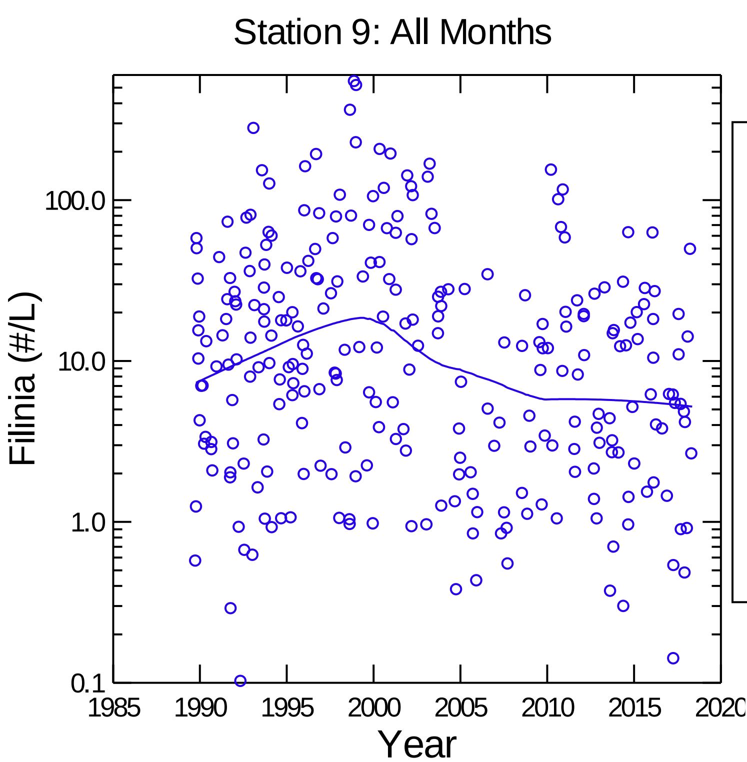
In the river, Conochilidae exhibited a strong increase in the early 1990’s similar to that observed in the cove (Figure 131). This was followed by a period of decline and recently a renewed increase. The trend line has gone from 3/L in 1990 to 35/L in 1995 to 10/L since 2005. When the entire period of record was examined, there was not a significant linear trend (Table 19).

Figure 131. Long term trend in Conochilidae. Station 9. River mainstem.



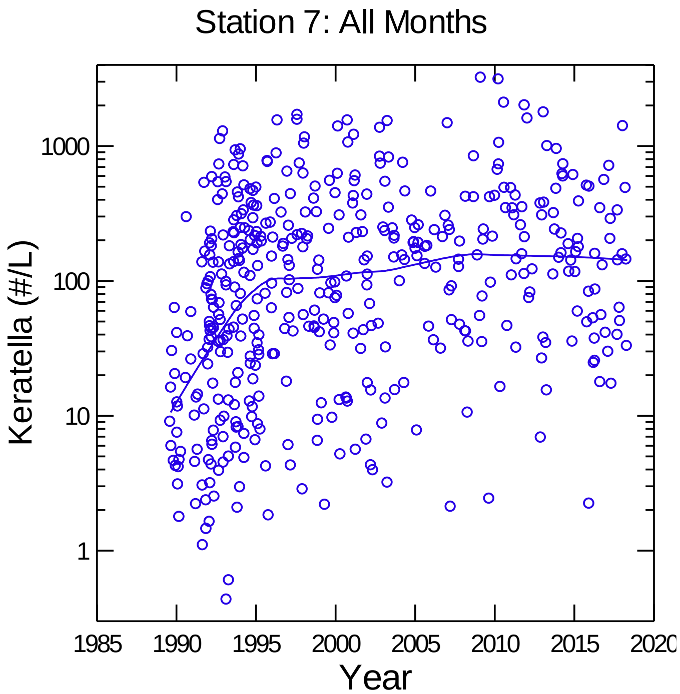
In the cove *Filinia* exhibited a steady increase from 1990 through 2000 rising from about 20/L to nearly 100/L (Figure 132). It has shown a gradual decline in recent years to about 30/L. When the entire period of record was considered, there is evidence for a linear increase in the cove despite the recent declines (Table 19).

Figure 132. Long term trend in *Filinia*. Station 7. Gunston Cove.



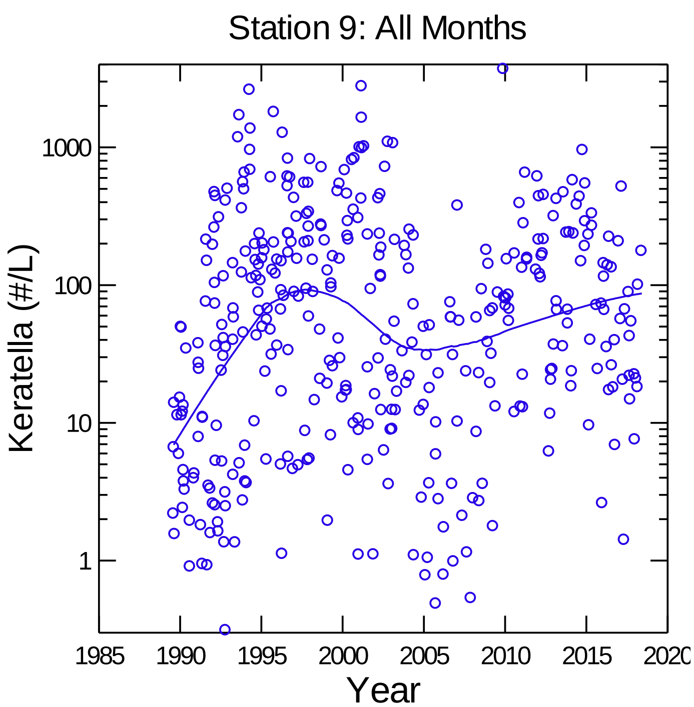
In the river *Filinia* demonstrated an increase through about 2001, declined from 2000-2005 and remained steady since. The trend line indicates about 5/L in 2017, about equal to the 7/L in 1990, but well below the peak of 20/L in 2000 (Figure 133). When the entire period of record was examined, there was a significant negative linear trend (Table 19).

Figure 133. Long term trend in *Filinia*. Station 9. River mainstem.



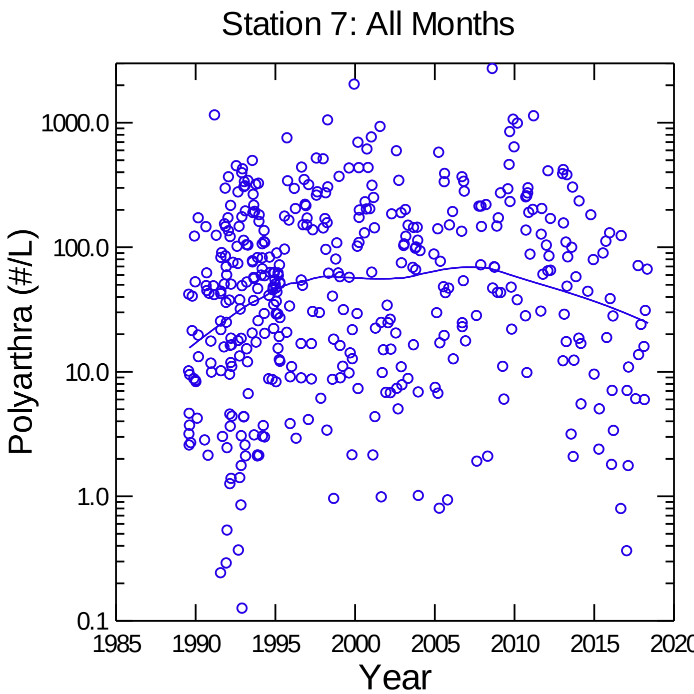
Keratella increased strongly from 1990 to 1995 and has shown a milder increase since then with the trend line approaching 200/L in 2018 (Figure 134). When the entire period of record was examined, there was a significant linear increase (Table 19).

Figure 134. Long term trend in *Keratella*. Station 7. Gunston Cove.



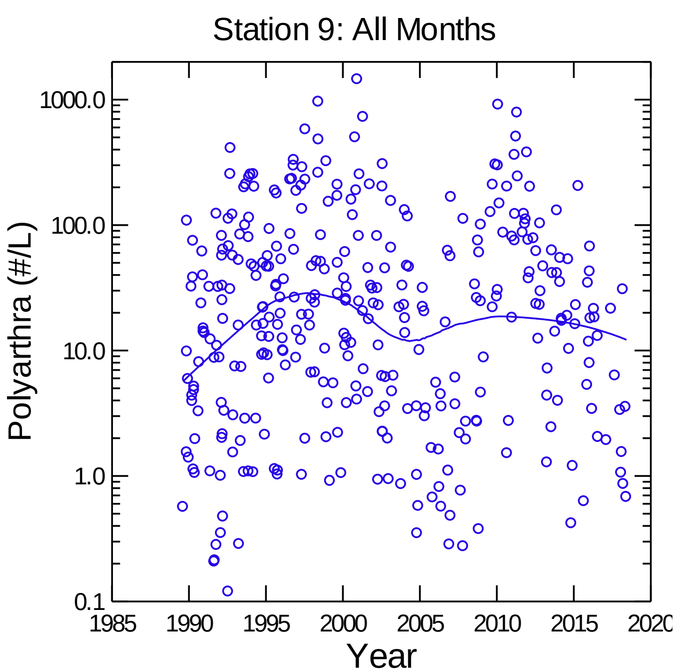
In the river *Keratella* increased from less than 10/L in 1990 to peak values of about 100/L in the mid to late 1990's (Figure 135). The trend line then declined to about 25/L, but since 2005 it has increased to about 100/L. Linear regression showed evidence of a linear increase when the entire study period was considered (Table 19).

Figure 135. Long term trend in *Keratella*. Station 9. River mainstem.



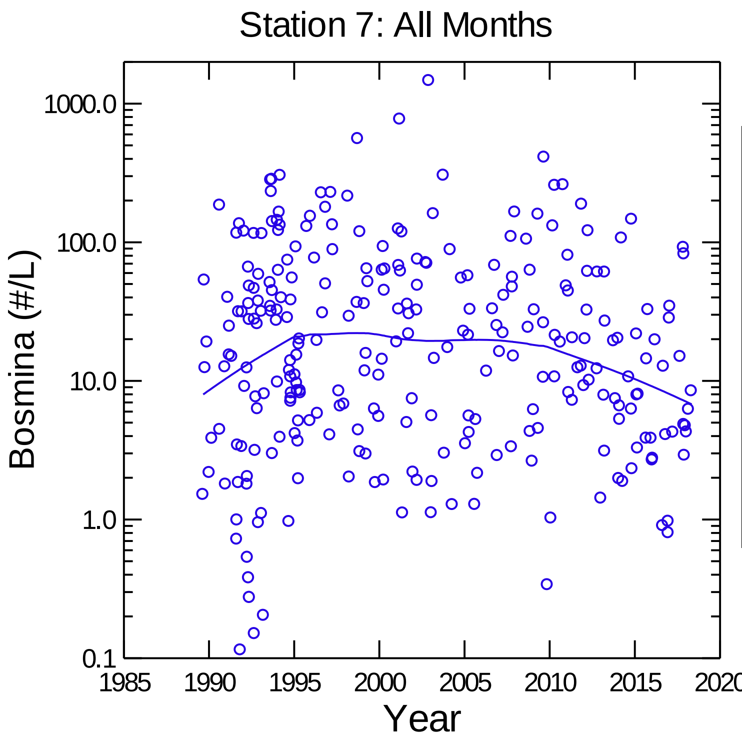
The trend line for *Polyarthra* in the cove increased steadily from 1990 to about 2000 rising from 15/L to about 60/L (Figure 136). Since 2000 densities have increased more slowly and now are dropping again reaching 25/L by 2018. Regression analysis indicated a barely significant linear increase when the entire period of record was examined (Table 19).

Figure 136. Long term trend in *Polyarthra*. Station 7. Gunston Cove.



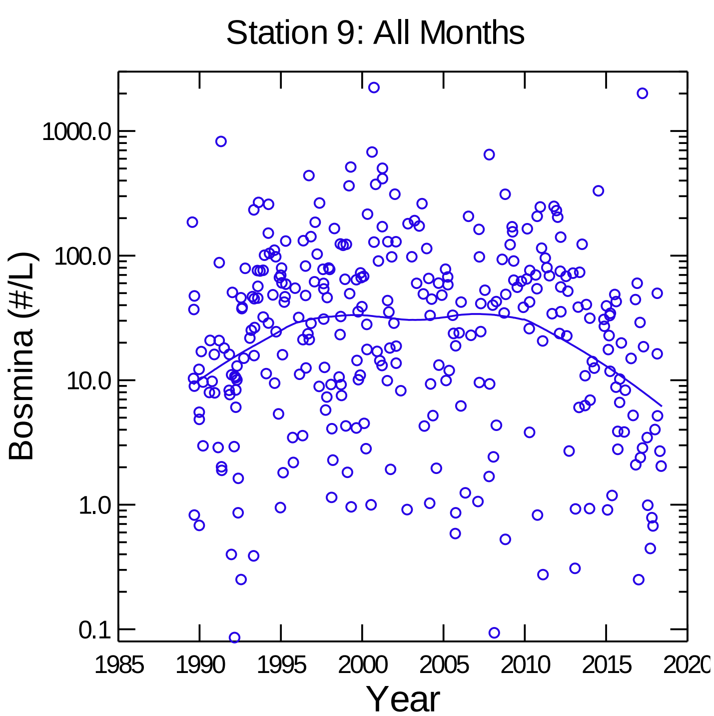
In the river *Polyarthra* showed a marked increase from 1990 to 2000 and then a decline to 2005. Recently values have increased again and by 2018 the trend line approached 10/L (Figure 137). Linear regression analysis did not indicate a significant positive trend over the period of record (Table 19).

Figure 137. Long term trend in *Polyarthra*. Station 9. River mainstem.



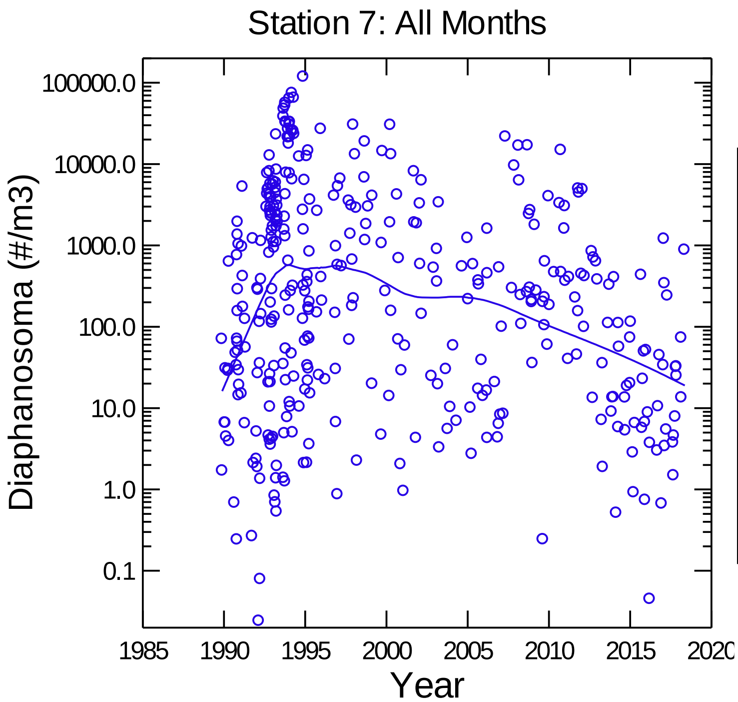
The trend line for *Bosmina* in the cove showed an increase from 8/L in 1990 to about 20/L in 2000 (Figure 138). Since 2000 densities have declined. Linear regression did not indicate a significant trend in the cove over the entire period of record (Table 19).

Figure 138. Long term trend in *Bosmina*. Station 7. Gunston Cove.



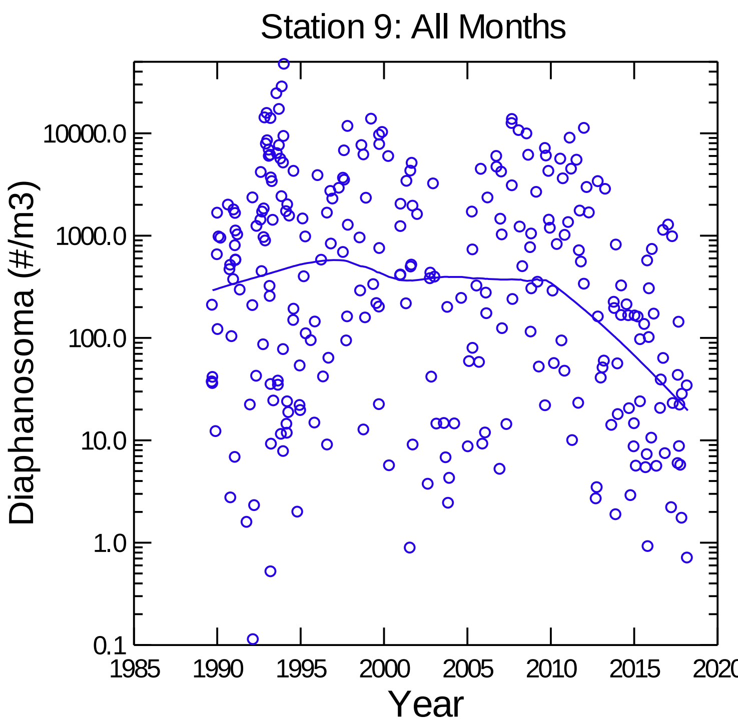
In the river mainstem the LOWESS curve for *Bosmina* increased from 1990 to 1995, and remained rather constant from 1995 to 2010 at about 30/L (Figure 139). Recently, it has declined. Regression analysis did not indicate a significant linear increase over the entire period of record (Table 19).

Figure 139. Long term trend in *Bosmina*. Station 9. River mainstem.



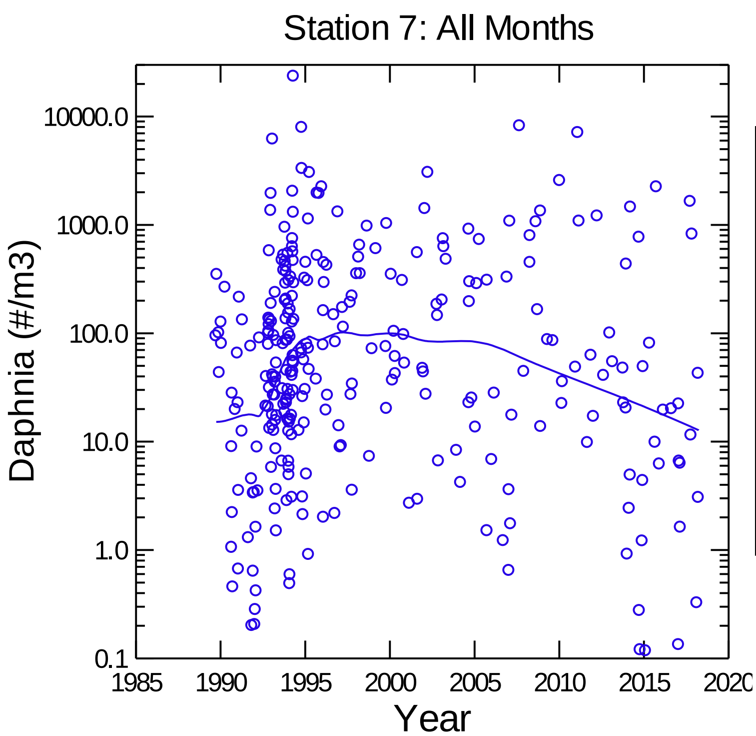
Diaphanosoma increased strongly in the early 1990s from about 12/m^3 nearly 1000/m^3. It gradually declined through 2016 to about 20/m^3 (Figure 140). Linear regression analysis of the entire period of record indicated a significant decline (Table 19).

Figure 140. Long term trend in *Diaphanosoma*. Station 7. Gunston Cove.



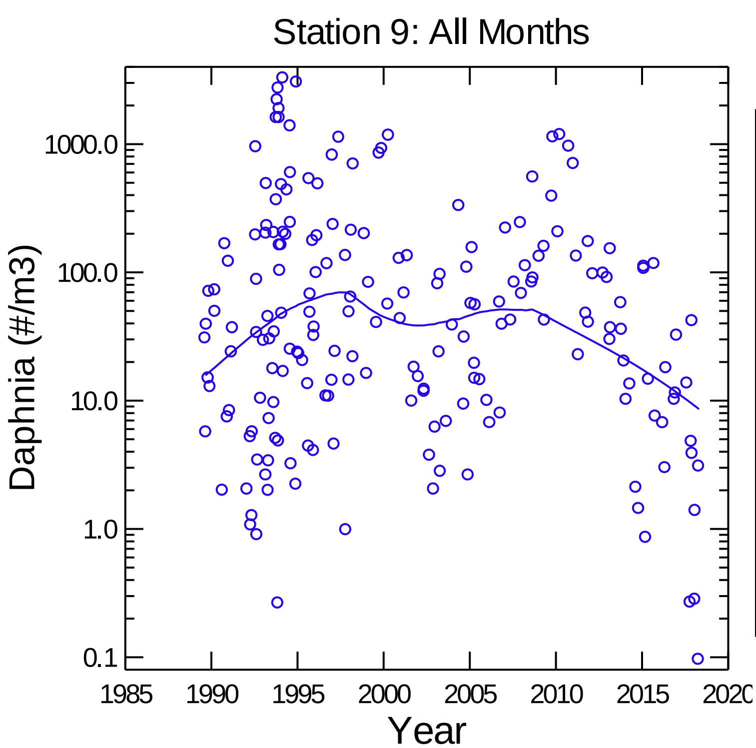
In the river the LOWESS line suggested a generally stable pattern in *Diaphanosoma* until 2010 until a decline set in (Figure 141). The trend line value of 20/m^3 found in 2018 compared with values as high as 600/m^3 in 1999. Regression analysis indicated significant declining trend over the period of record (Table 19).

Figure 141. Long term trend in *Diaphanosoma*. Station 9. River mainstem.



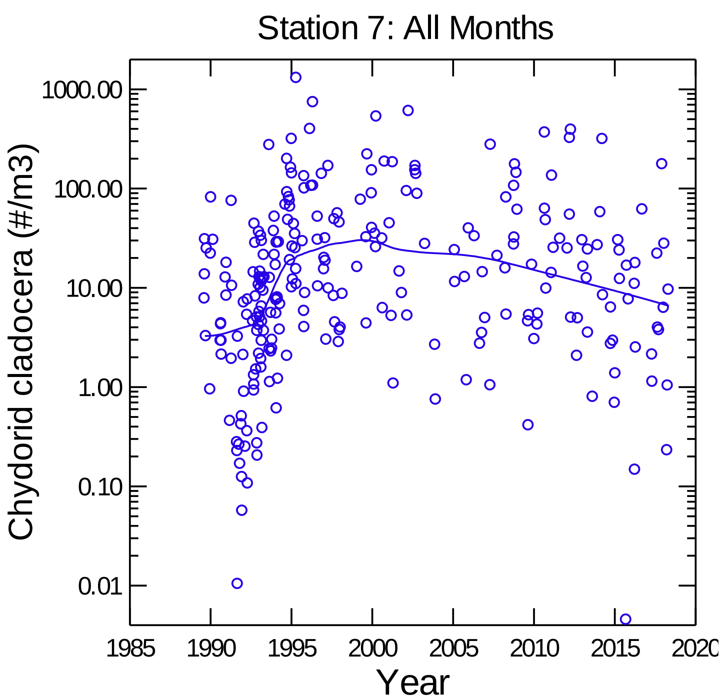
Daphnia in the cove has declined slowly since 1995 from about 100/m^3 to 10/m^3 in 2018 (Figure 142). Regression analysis examining the entire period of record was not significant (Table 19).

Figure 142. Long term trend in *Daphnia*. Station 7. Gunston Cove.



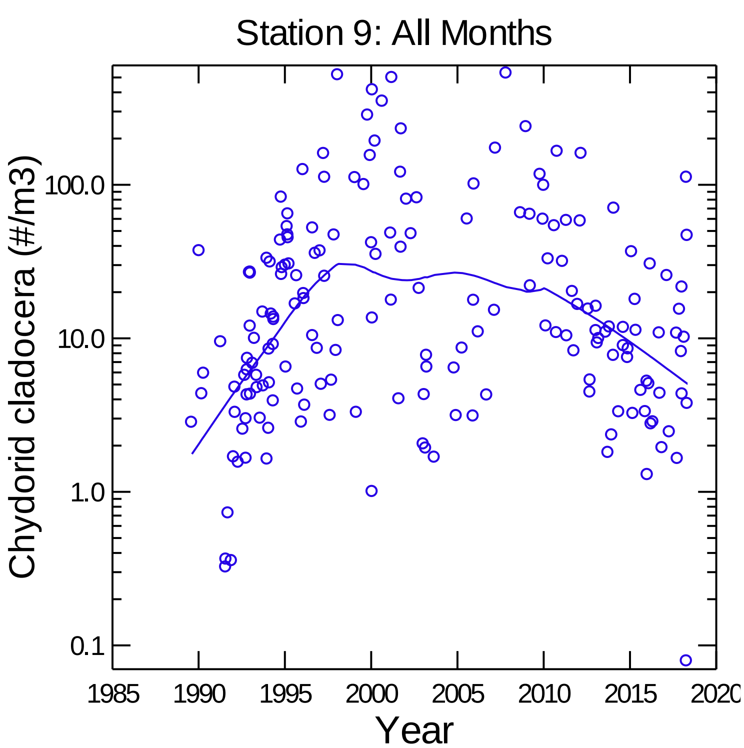
Daphnia in the river increased early on, but has since declined slightly (Figure 143). The trend line in 2018 dropped below 10/m^3, even lower than the level observed at the beginning of the record in 1990. Regression analysis did indicated a significant negative trend over the study period (Table 19).

Figure 143. Long term trend in *Daphnia*. Station 9. River mainstem.



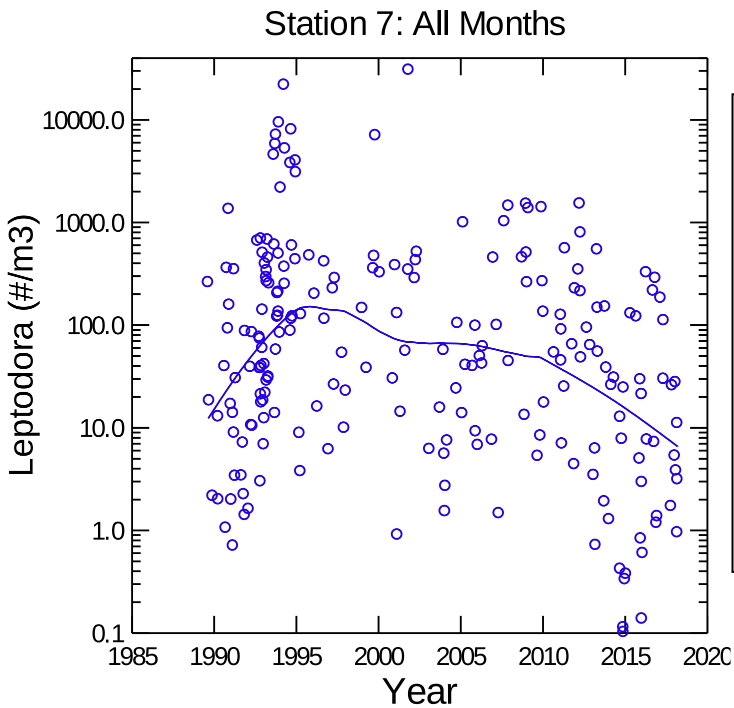
Chydorid cladocera in the cove have maintained a consistent population of about 8-10/m^3, substantially higher than the low of 4/m^3 in the early 1990's, but below trend line values of 30/m^3 observed in 2000 (Figure 144). Regression analysis did not show a significant temporal trend (Table 19).

Figure 144. Long term trend in Chydorid Cladocera. Station 7. Gunston Cove.



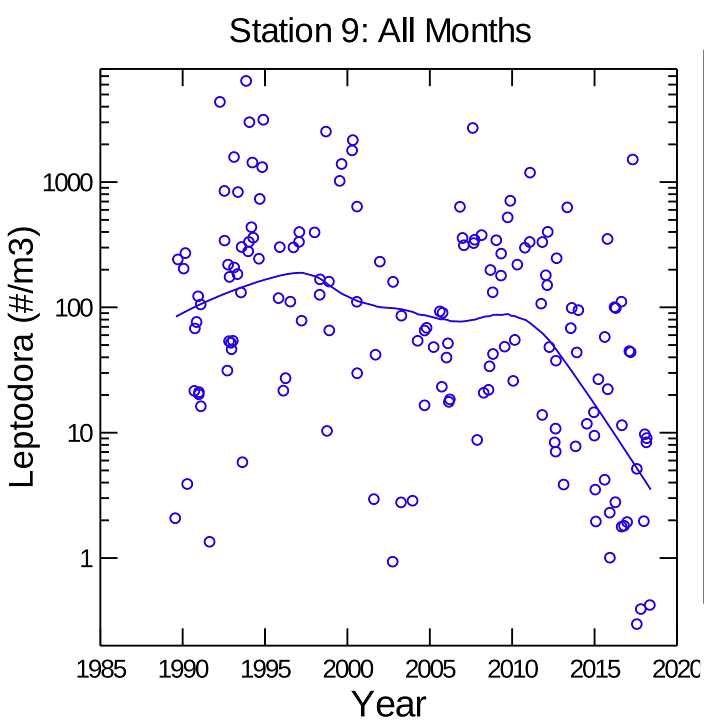
In the river chydorids continued a decrease to about 5/m^3, slightly above the low of about 2/m^3 in the early 1990's (Figure 145). There was no evidence for a significan linear trend (Table 19).

Figure 145. Long term trend in Chydorid Cladocera. Station 9. River mainstem.



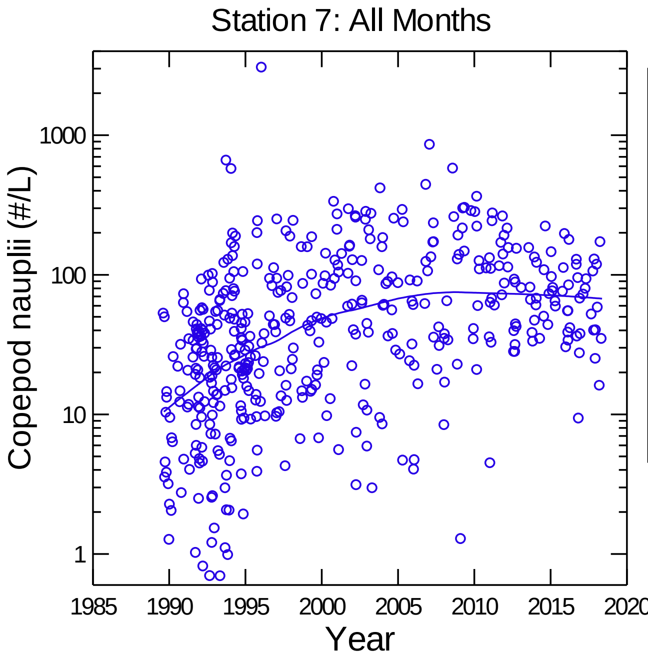
In the cove the trend line for *Leptodora*, the large predaceous cladoceran, has gradually decreased to about 8/m^3, down from its high of about 150/m^3 in 1994, and similar the 1990 value (Figure 146). There was evidence for a significant negative linear trend in *Leptodora* over the entire study period (Table 19).

Figure 146. Long term trend in *Leptodora*. Station 7. Gunston Cove.



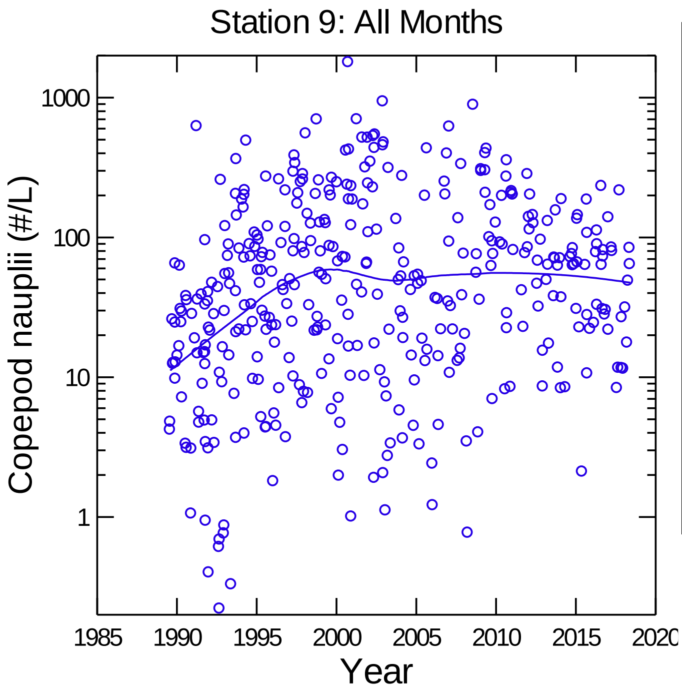
In the river, *Leptodora* densities continued a general decline which began in 1995 resulting in trend line values of about 4/m^3 for 2018 (Figure 147). These values are well below the peak of 200/m^3 in 1994. Linear regression analysis detected a significant negative linear trend when the whole study period was considered (Table 19).

Figure 147. Long term trend in *Leptodora*. Station 9. River mainstem.



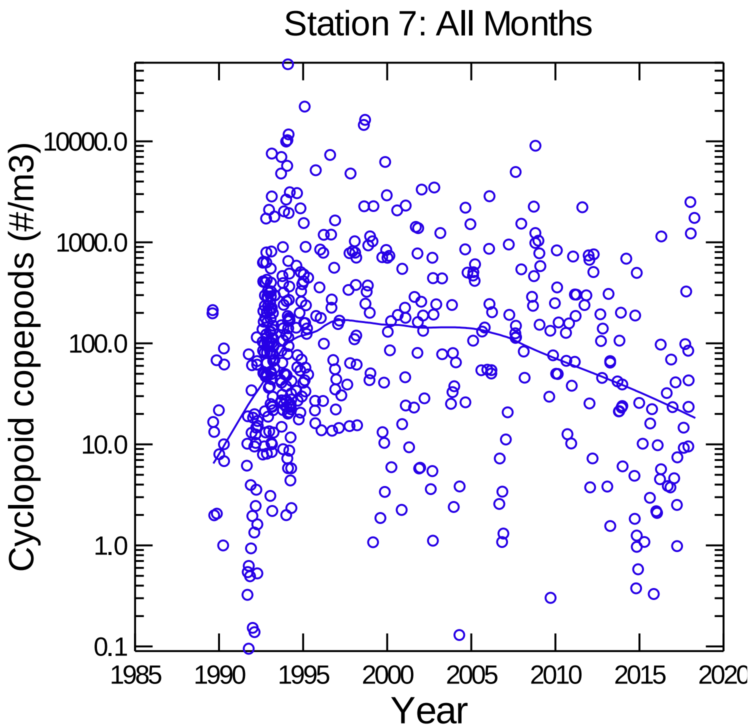
Copepod nauplii, the immature stages of copepods, have shown a positive trend since inception, but it is now leveling at about 80/L (Figure 148). These values are well above the initial values of about 10/L in 1990. A strong linear increase was observed over the study period (Table 19).

Figure 148. Long term trend in Copepod Nauplii. Station 7. Gunston Cove.



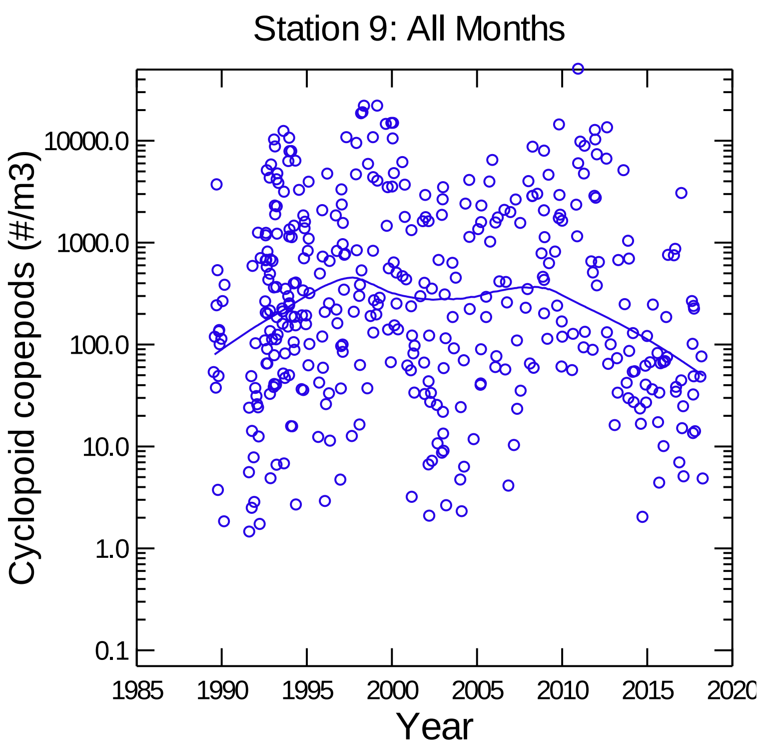
In the river, copepod nauplii showed a a similar leveling of an upward trend (Figure 149). The 2018 LOWESS trend line value was about 50/L, up from an initial value of 10/L in 1990, similar to the previous peak. A significant linear increase was found for nauplii over the study period (Table 19).

Figure 149. Long term trend in Copepod Nauplii. Station 9. River mainstem.



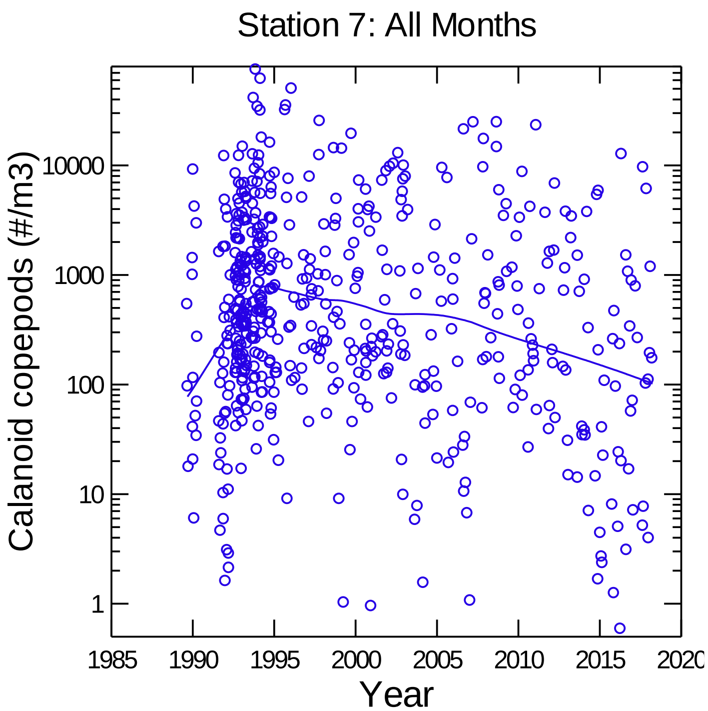
In the cove, cyclopoid copepods increased strongly in the early 1990's, were steady from 1995 to 2005 at about 200/m^3, and since have decreased slowly to about 20/m^3 (Figure 150). Cyclopoid copepods did not exhibit a significant linear trend in the cove over the study period (Table 19).

Figure 150. Long term trend in Cyclopoid Copepods. Station 7. Gunston Cove



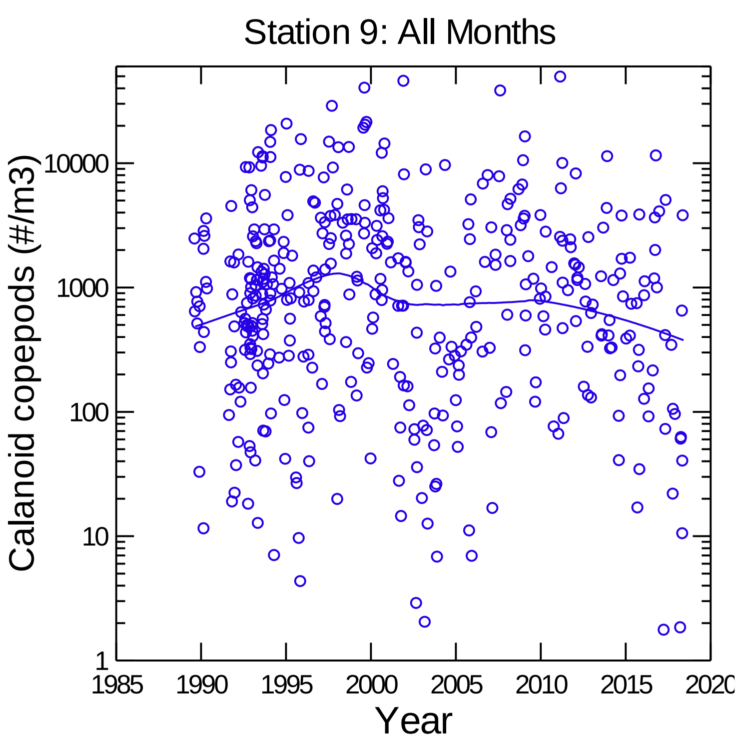
Cyclopoid copepods have shown several cycles over the period (Figure 151). The trend line has varied from 90/m^3 to about 400/m^3. In 2018 cyclopoids were at a low point. No linear increase was found when the entire study period was considered (Table 19).

Figure 151. Long term trend in Cyclopoid Copepods. Station 9. River mainstem



Calanoid copepods (Figure 152) in the cove increased greatly in the early 1990's to near 1000/m^3 and then have gradually declined to about 100/m^3. A significant negative trend was revealed by regression analysis.

Figure 152. Long term trend in Calanoid Copepods. Station 7. Gunston Cove



In the river calanoid copepods have varied a lot over the years, but the trend line has changed only gradually and was at 400/m^3 in 2018 (Figure 153). There was not a statistically significant linear trend.

Figure 153. Long term trend in Calanoid Copepods. Station 9. River mainstem

E. Ichthyoplankton Trends: 1993-2018

Ichthyoplankton monitoring provides a crucial link between nutrients, phytoplankton, zooplankton and juvenile fishes in seines and trawls. The ability of larvae to find food after yolk is consumed may represent a critical period when survival determines the abundance of a year-class. The timing of peak density of feeding stage fish larvae is a complex function of reproductive output as well as the temperature and flow regimes. These peaks may coincide with an abundance or scarcity of zooplankton prey. When the timing of fish larva predators overlaps with their zooplankton prey, the result is often a high abundance of juveniles that can be observed in high density in seines and trawl samples from throughout the cove. In addition, high densities of larvae but low juvenile abundance may indicate that other factors (e.g., lack of significant refuge for settling juveniles) are modifying the abundance of a year-class.

The dominant species in the ichthyoplankton samples, namely Clupeids (which are primarily river herring and Gizzard Shad), *Morone* sp. (mostly White Perch), Atherinids (Inland Silversides), and Yellow Perch, all exhibited a spike in density in 1995 followed by a decline in numbers until about 2008. The declines in Clupeid larvae were followed by increases starting in 2010 (Figure 154; Table 20). Especially 2010-2012 showed very high density of these larvae, while numbers decreased again in 2013. With continued relatively low densities from 2014 to 2016, the high densities of 2010-2012 appear to be a peak rather than a rebound to higher densities. The trend goes up a bit again in 2017, but this increase was unfortunately not continued in 2018. It is possible that this is natural variation, and that these populations rely on a few highly successful yearclasses. A moratorium on river herring since 2012 may be allowing the numbers to increase over time.

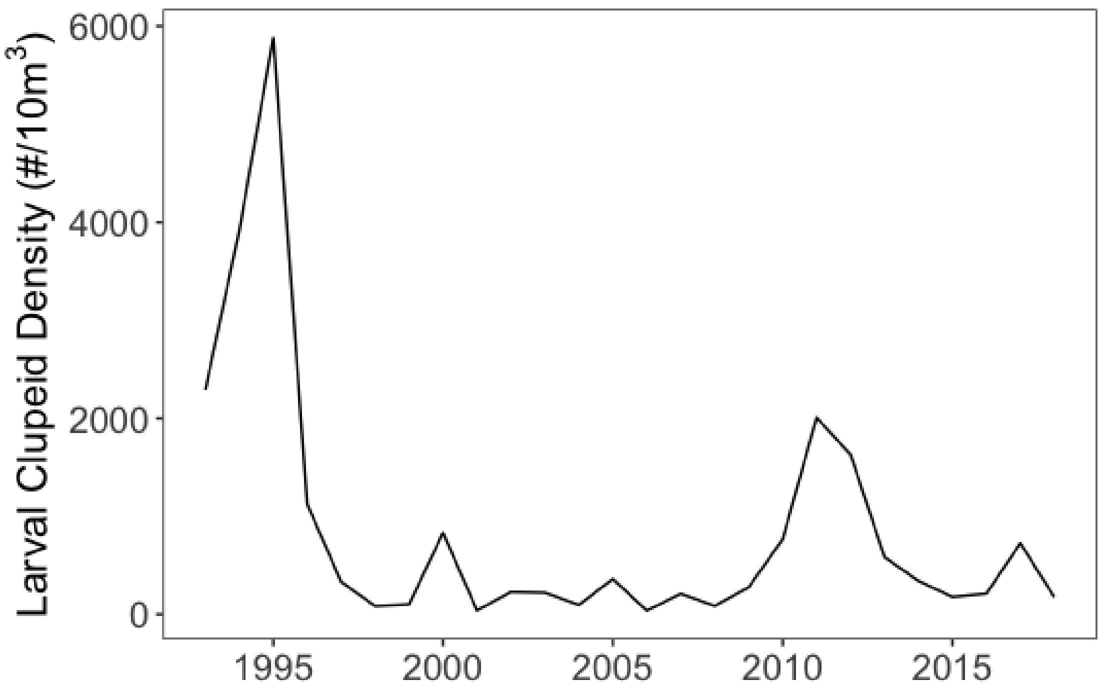


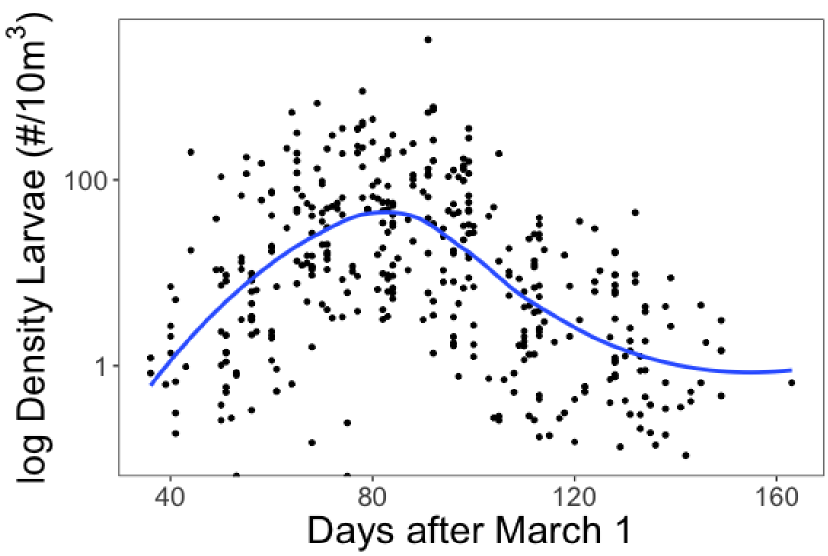
Figure 154. Long-term trend in Clupeid Larvae (*Alosa sp.* and *Dorosoma sp.*; abundance 10 m^{-3}).

Table 20. Density of larval fishes Collected in Gunston Cove and the Potomac mainstem (abundance 10 m^{-3}).

Year	***Alosa* species**	**Gizzard Shad**	**All Sunfish**	***Morone* species**	**Yellow Perch**	**Inland Silverside**
2018	72	38	4	4	0	3
2017	312	148	41	62	1	5
2016	105	87	2	87	0	7
2015	41	29	0	2	0	21
2014	102	115	0	61	0	0
2013	133	220	3	112	1	1
2012	476	1395	0	330	0	0
2011	149	2007	0	62	0	0
2010	247	1032	0	88	15	10
2009	38	276	0	58	0	2
2008	0	0	0	0	1	1
2007	17	209	0	40	12	5
2006	9	37	0	8	20	8
2005	88	280	0	35	0	3
2004	245	94	0	42	0	5

2003	110	170	0	30	6	4
2002	998	30	0	28	1	1
2001	95	5	0	3	0	1
2000	8	97	0	128	2	102
1999	435	94	3	63	0	13
1998	674	84	1	115	3	0
1997	1305	265	31	146	6	8
1996	834	1118	0	571	91	0
1995	721	810	10	333	8	9
1994	640	202	38	176	0	57
1993	33	298	1	112	1	15

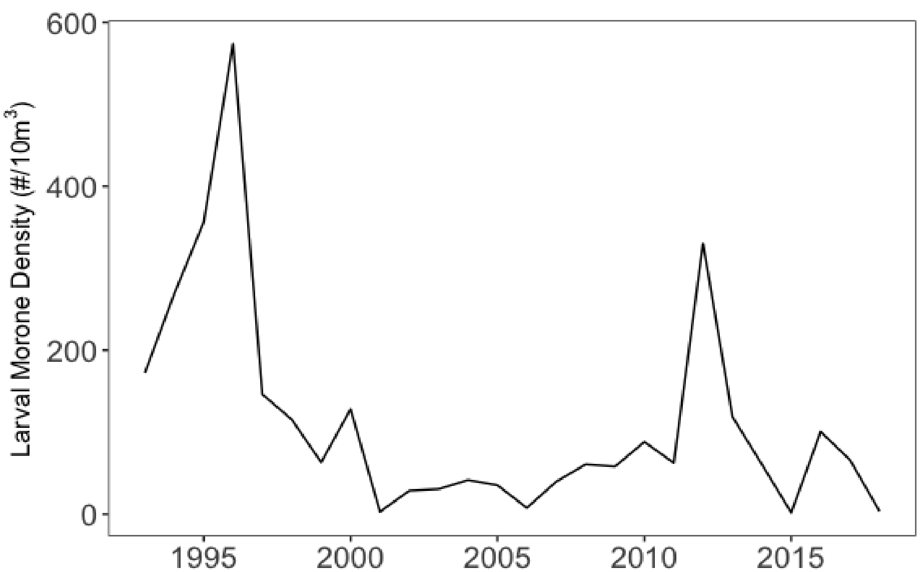
The peaks in abundance over the season reflect characteristic spawning times of each species (Figures 155, 157, 159, and 161). Clupeid larval density shows a distinct peak mid-May (Figure 155). Clupeid larvae are dominated by Gizzard Shad, which spawns later in the season than river herring (Alewife and Blueback Herring). However, river herring larvae are part of this peak as well; although their spawning season is from mid-March to mid-May, spawning occurs higher upstream, and larvae subsequently drift down to Gunston Cove. The earliest peak is from Yellow Perch (Figure 147), which may even be at its highest before our sampling starts. An early peak is also seen for *Morone sp*., which is mostly White Perch (Figure 143). White Perch begin spawning early and larval densities slowly taper off. Consequently, White Perch larvae are found throughout most of the sampling season. Silversides have a less pronounced peak in late May/early June, with low densities continuing to be present throughout the season (Figure 145).



The seasonal pattern in clupeid larvae for 1993-2018 (Figure 155) shows that a peak in density occurs about 80 days after March 1, or mid-May.

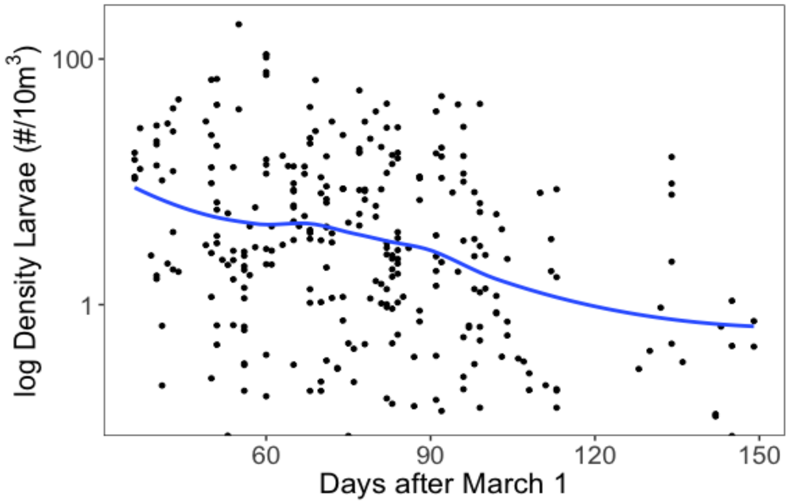
Figure 155. Seasonal pattern in Clupeid larvae (*Alosa sp.* and *Dorosoma sp.*; abundance 10 m^{-3}). The x-axis represents the number of days after March 1.

The long-term trend in annual average density of *Morone* larvae shows a high similarity with that of Clupeid larvae (Figure 156). While densities are lower, the same pattern of high peaks in 1995 and 2012, and low densities in other years is seen. Looking at the seasonal pattern (Figure 157), we may miss high densities of larvae occurring in spring, as our sampling of larvae in Gunston Cove starts mid-April. With the high abundance of juveniles and adults each year, our *Morone* larval sample is likely not representative of the total larval production. White perch is also a migratory species, and juveniles may come in the system from elsewhere.



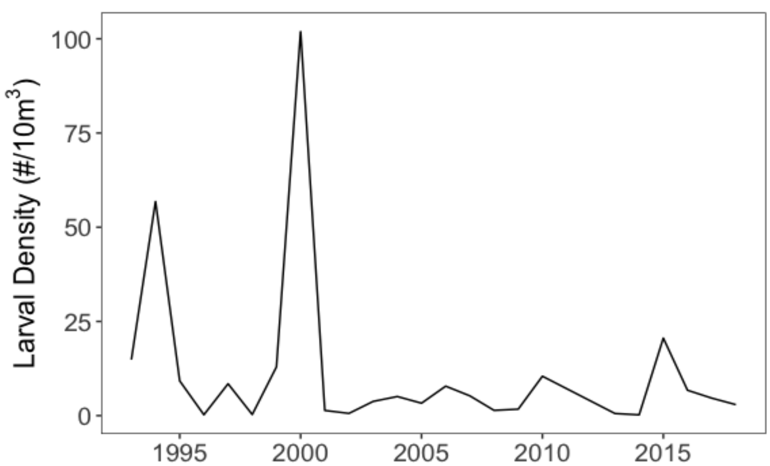
The trend in number of White Perch and Striped Bass larvae per 10 m^3 since 1993 is depicted in the graph in Figure 156. Two peaks are observed in 1995 and 2012 with low densities in other years.

Figure 156. Long term trend in *Morone sp.* larvae (abundance 10 m^{-3}).



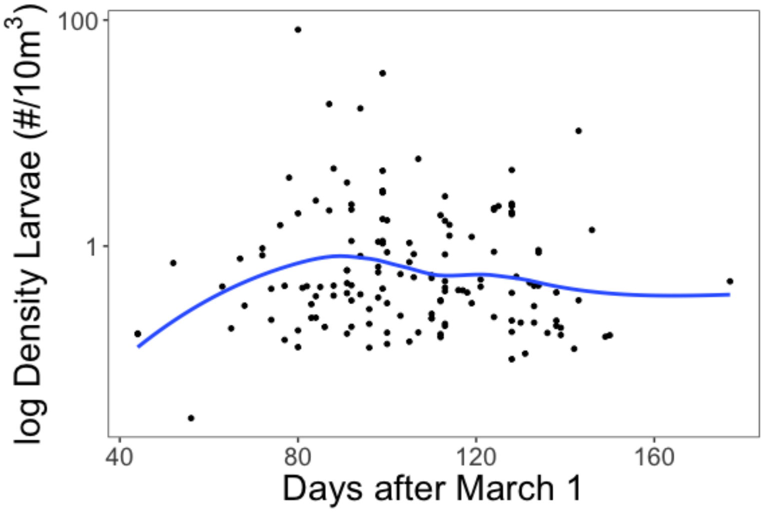
The seasonal density of *Morone* sp. larvae per 10 m^3 is shown in Figure 157. Highest densities are at the start of the sampling season.

Figure 157. Seasonal pattern in *Morone sp.* larvae (abundance 10 m^{-3}). X-axis represents days after March 1st.



The long-term trend in density of Inland Silverside is presented in Figure 158. After a high peak in 2000, densities have been moderate to low with some small peaks in 2006, 2010, and 2015.

Figure 158. Long-term trend in *Menidia beryllina* larvae (abundance 10 m^{-3}).

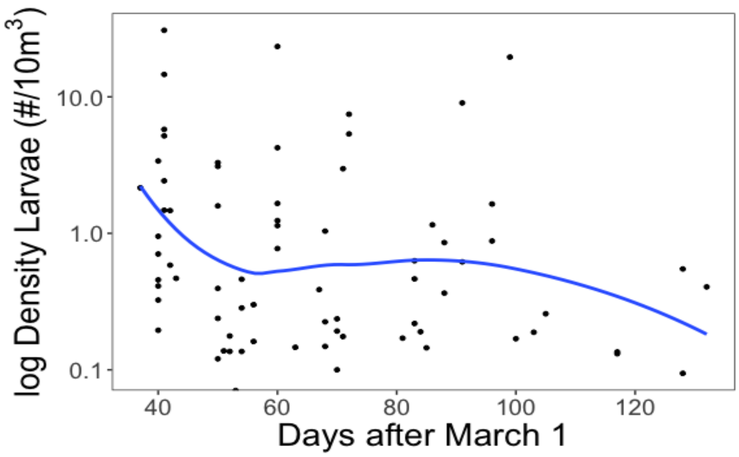


The seasonal occurrence of Inland Silverside per $10m^3$ is shown in a LOWESS graph in Figure 159. The pattern shows maximum density around 90 days after March 1, or around the first week of June.

Figure 159. Seasonal pattern in *Menidia beryllina* larvae (abundance 10 m^{-3}). The x-axis represents the number of days after March 1.

The long-term trend in density of Yellow Perch larvae since 1993 (Figure 160). Following unusually high densities in 1996, abundances decreased to low values, especially since 2011.

Figure 160. Long-term trend in *Perca flavescens* larvae (abundance 10 m^{-3}).



The long-term pattern of seasonal occurrence of Yellow Perch larval density is presented in Figure 161. The greatest densities occur in early to mid-April, while spawning continues producing low densities throughout the season. Total density is low, which is likely the main reason for this unpronounced spawning pattern.

Figure 161. Seasonal pattern in *Perca flavescens* larvae (abundance 10 m^{-3}). The x-axis represents the number of days after March 1.

F. Adult and Juvenile Fish Trends: 1984-2018

Trawls

Overall patterns

Annual abundance of juvenile fishes inside Gunston Cove is indexed by mean catch per trawl in the inner cove (stations 7 and 10 combined; Table 21, Figure 162). Since 1984, this index has fluctuated by over an order of magnitude, and the pattern was predominately due to changes in the catch rate of White Perch (Figure 162). The one high peak in 2004 that was not caused by high White Perch abundance was caused by a large catch of Blueback Herring (Figure 163). The small divergence in 2018 (small total catch increase with small White Perch decrease) was caused by a high catch of Spottail Shiner. On average, catch rates of fishes within the cove are approximately the same over the time of the survey; in other words, there is no significant increasing or decreasing trend over time. The overall catch rate for the inner cove (stations 7 and 10) in 2018 is similar to previous years and about the same as the start of the survey. Trawl catches in station 7 and 10 were dominated by White Perch and Spottail Shiner. Tessellated Darter was represented in the catches with high abundance as well.

Strong cohorts punctuated White Perch catch rates in 1993, 2007, 2010, 2012, and 2015. Overall, White Perch catches have remained similar and stable over the period of record. The higher frequency of strong year-classes after 2005 results in an overall small increase in trend starting that time.

Table 21. Mean catch per trawl of adult and juvenile fishes at Stations 7 and 10 combined. 1984-2018.

Year	All Species	White Perch	All Alosa Sp.	Blueback Herring	Alewife	Gizzard Shad	Bay Anchovy	Spottail Shiner	Brown Bullhead	Pumpkinseed
2018	147.1	79.1	2.7	0.0	0.4	0.2	0.0	30.5	0.8	4.8
2017	151.7	106.5	1.2	0.0	0.5	0.0	0.0	11.7	0.1	6.2
2016	170.4	121.7	12.7	0.0	0.1	0.1	0.3	13.7	0.3	1.2
2015	284.2	172.3	34.4	26.1	4.2	0.2	0.1	64.4	0.1	1.1
2014	92.3	46.2	10.4	2.1	1.3	0.2	1.4	15.6	0.3	0.5
2013	158.8	97.9	13.1	6.8	2.9	0.1	1.4	31.0	0.6	1.8
2012	164.5	128.7	1.7	0.1	0.2	3.3	0.4	11.8	0.6	2.1
2011	96.8	43.5	3.3	0.1	1.2	0.2	0.0	19.9	0.1	2.0
2010	372.9	248.1	109.1	0.2	52.9	2.2	0.4	6.0	0.5	1.4
2009	93.7	18.3	46.6	1.0	45.2	0.6	6.2	2.7	0.1	3.1
2008	69.8	16.1	0.2	0.0	0.0	4.0	0.2	2.5	0.6	7.0
2007	227.2	141.4	37.2	23.6	8.8	0.2	15.8	20.1	0.2	2.6
2006	26.1	9.6	2.7	1.6	0.6	0.2	2.3	3.0	0.4	1.8
2005	68.4	20.9	33.1	11.8	16.4	1.1	0.0	6.5	0.4	1.4
2004	408.4	23.4	373.2	337.5	33.1	0.9	0.6	8.0	0.0	0.5
2003	54.2	13.2	23.9	18.8	3.5	0.0	7.4	2.8	0.1	0.4
2002	80.1	15.1	39.5	9.8	28.5	0.1	15.8	0.6	0.0	1.7
2001	143.5	47.0	50.6	40.5	9.9	0.3	35.1	2.8	3.3	1.4
2000	68.0	53.3	5.4	3.6	1.9	2.3	1.7	1.3	1.9	0.6
1999	86.9	63.2	4.7	4.2	0.5	1.0	5.4	4.8	2.4	1.8
1998	83.2	63.8	3.0	2.2	0.8	0.5	3.7	6.4	0.9	1.6
1997	81.4	61.6	2.9	1.9	1.0	5.0	2.6	2.9	1.5	1.4
1996	54.1	37.1	8.5	4.0	4.4	0.5	0.2	2.6	0.5	2.0
1995	90.4	71.1	6.2	4.1	2.1	0.4	3.0	2.9	2.1	1.9
1994	102.8	77.7	6.5	6.5	0.0	0.4	1.1	6.3	2.4	2.6
1993	246.6	216.0	2.0	1.4	0.6	1.4	0.6	7.3	4.5	3.4

1992	112.8	81.5	0.2	0.2	0.0	0.9	0.8	2.4	11.5	5.1
1991	123.1	91.5	1.4	0.9	0.5	7.6	2.5	2.7	11.6	1.7
1990	68.8	31.6	24.1	21.1	3.1	0.1	1.1	1.1	9.0	0.5
1989	78.2	14.9	16.4	16.1	0.2	42.1	0.2	0.5	3.0	0.6
1988	126.6	74.5	20.3	10.5	7.0	13.5	8.3	1.9	5.2	0.7
1987	109.2	54.6	19.6	16.4	3.2	5.6	8.8	0.7	17.2	1.4
1986	130.9	69.9	24.6	1.8	22.7	4.2	4.0	1.2	18.1	0.6
1985	135.9	43.9	25.8	8.6	10.7	2.9	48.2	1.1	9.8	0.1
1984	213.2	127.4	11.9	6.0	0.6	13.3	22.0	1.5	32.9	0.2

Table 22. Mean catch per trawl of selected adult and juvenile fishes for all months at Station 9. 1988-2018

Year	All Species	All Alosa Sp.	Alewife	Blueback Herring	White Perch	Bay Anchovy	Spottail Shiner	Brown Bullhead	Blue Catfish	Channel Catfish	Tesselated Darter
2018	41.8	0.0	0.0	0.0	27.6	0.0	1.6	0.7	8.5	0.0	1.8
2017	9.0	0.1	0.0	0.0	8.5	0.0	0.0	0.0	0.2	0.0	0.0
2016	10.1	2.0	0.0	0.0	2.0	4.9	0.0	0.0	1.2	0.0	0.0
2015	15.8	10.3	7.8	0.2	1.5	0.5	0.2	0.2	2.8	0.2	0.0
2014	16.9	6.8	3.7	1.1	3.0	3.3	0.1	0.1	3.1	0.0	0.4
2013	12.2	3.9	2.1	0.6	1.5	1.6	0.0	0.0	4.5	0.0	0.2
2012	62.1	0.0	0.0	0.0	21.6	31.7	0.8	0.0	7.3	0.3	0.0
2011	33.9	0.4	0.2	0.0	21.2	0.0	0.2	0.1	5.1	6.4	0.3
2010	38.7	0.1	0.0	0.0	10.8	7.9	0.0	0.1	19.5	0.0	0.0
2009	34.6	2.3	0.5	0.4	13.7	7.6	0.5	0.2	8.7	0.6	0.1
2008	118.7	0.1	0.0	0.0	13.9	99.9	0.6	0.1	3.7	0.0	0.0
2007	253.8	52.7	17.2	2.5	195.7	0.7	1.1	0.0	1.8	0.0	0.9
2006	68.1	0.2	0.0	0.2	31.0	3.0	0.2	8.0	19.9	4.6	0.0

2005	95.0	15.4	14.3	1.1	36.5	12.1	1.8	2.1	18.3	4.7	0.1
2004	41.9	3.8	3.4	0.3	20.4	0.0	1.1	0.0	5.2	6.6	0.3
2003	65.8	0.3	0.1	0.1	32.6	0.0	0.6	0.0	7.4	14.4	1.2
2002	55.2	1.2	0.7	0.4	28.2	0.5	0.1	0.0	6.8	10.8	1.0
2001	77.1	0.1	0.1	0.1	40.1	22.2	0.1	0.9	2.7	5.5	0.8
2000	52.1	0.1	0.1	0.0	43.4	0.0	0.1	2.1	0.0	3.9	0.0
1999	23.1	0.0	0.0	0.0	18.9	0.2	0.0	0.2	0.0	2.4	0.0
1998	22.3	0.1	0.1	0.0	12.9	0.4	0.1	0.2	0.0	6.2	2.0
1997	50.1	0.0	0.0	0.0	37.8	0.0	1.1	0.4	0.0	9.1	0.4
1996	13.8	0.0	0.0	0.0	7.0	0.0	0.1	0.1	0.0	5.7	0.8
1995	30.5	0.3	0.3	0.0	16.8	0.2	0.2	4.2	0.0	8.0	0.1
1994	32.0	0.0	0.0	0.0	13.4	0.1	0.0	2.4	0.0	6.4	3.5
1993	31.2	0.1	0.0	0.1	6.4	0.0	6.2	1.4	0.0	6.8	7.5
1992	29.0	0.1	0.0	0.1	13.4	0.0	0.2	1.1	0.0	1.8	3.3
1991	70.9	0.1	0.1	0.0	43.7	2.0	0.1	1.1	0.0	15.9	0.2
1990	102.8	0.1	0.1	0.0	50.8	0.0	0.1	5.1	0.0	40.9	0.1
1989	14.2	1.0	0.2	0.8	7.8	0.4	0.0	1.5	0.0	1.9	0.3
1988	19.2	0.2	0.2	0.0	5.2	11.5	0.0	0.0	0.0	0.8	0.0
1986	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 23. Mean catch per trawl of selected adult and juvenile fishes for all months at Stations 7, 9, and 10 combined. 1984-2018.

Year	All Species	White Perch	All Alosa Sp.	Blueback Herring	Alewife	Gizzard Shad	Bay Anchovy	Spottail Shiner	Brown Bullhead	Blue Catfish	Channel Catfish
2018	106.3	59.2	1.6	0.0	0.2	0.1	0.0	19.3	0.7	3.4	0.0
2017	89.6	63.9	0.7	0.0	0.3	0.0	0.0	6.6	0.0	0.2	0.0
2016	103.6	71.8	8.2	0.0	0.0	0.0	2.2	8.0	0.2	0.5	0.0
2015	161.2	94.0	23.3	14.2	5.8	0.1	0.2	35.0	0.1	1.3	0.1
2014	62.1	28.9	8.9	1.7	2.3	0.1	2.2	9.4	0.2	1.3	0.0

2013	102.4	60.8	9.6	4.4	2.6	0.2	1.5	19.1	0.4	2.3	0.0
2012	123.5	85.8	1.0	0.0	0.1	2.0	12.9	7.4	0.4	2.9	0.2
2011	74.5	35.6	2.3	0.1	0.9	0.1	0.0	12.9	0.1	2.0	2.3
2010	247.6	159.1	68.2	0.1	33.0	1.4	3.2	3.8	0.3	7.9	0.0
2009	73.4	16.7	31.4	0.8	29.9	0.4	6.7	1.9	0.2	3.0	0.3
2008	83.8	15.5	0.1	0.0	0.0	2.9	28.7	2.0	0.4	1.2	0.0
2007	236.1	159.5	42.4	16.6	11.6	0.1	10.7	13.8	0.1	0.7	0.0
2006	41.1	17.2	1.8	1.1	0.4	0.1	2.5	2.0	3.1	7.1	1.6
2005	77.8	26.5	26.8	8.0	15.6	0.7	4.3	4.9	1.0	7.0	1.8
2004	271.0	22.3	234.7	211.1	22.0	0.5	0.4	5.4	0.0	2.0	2.5
2003	58.1	19.7	16.0	12.6	2.3	0.0	4.9	2.1	0.1	2.5	5.4
2002	71.7	19.6	26.5	6.6	19.0	0.1	10.6	0.4	0.0	4.1	4.6
2001	122.3	44.8	34.5	27.6	6.8	0.3	31.0	1.9	2.5	0.9	1.8
2000	65.3	48.8	4.2	2.3	1.9	1.5	1.1	2.1	1.9	0.0	1.3
1999	65.6	48.4	3.1	2.8	0.3	0.7	3.7	3.2	1.7	0.0	0.8
1998	62.9	46.8	2.0	1.4	0.6	0.4	2.6	4.3	0.7	0.0	2.1
1997	71.0	53.6	2.0	1.3	0.7	3.3	1.7	2.3	1.1	0.0	3.1
1996	36.0	23.7	4.5	2.1	2.3	0.3	0.1	1.5	0.3	0.0	2.4
1995	78.8	58.4	3.7	2.4	1.3	1.2	2.9	2.2	1.9	0.0	4.7
1994	90.5	68.1	2.4	2.3	0.1	0.3	0.8	6.5	1.4	0.0	2.1
1993	162.4	131.7	2.3	2.0	0.4	1.0	2.2	7.6	1.9	0.0	2.1
1992	119.8	88.2	1.3	0.6	0.7	0.4	1.0	2.3	4.5	0.0	1.5
1991	148.9	82.4	17.5	12.5	5.0	5.3	26.2	2.8	4.5	0.0	2.8
1990	67.5	31.2	19.1	16.1	3.0	0.1	0.8	2.5	4.0	0.0	6.9
1989	62.4	9.1	26.4	25.8	0.6	20.8	0.6	0.4	1.4	0.0	0.6
1988	79.5	32.9	18.8	14.4	3.3	6.9	13.7	1.2	2.4	0.0	0.3
1987	104.1	49.7	15.3	14.1	1.2	6.5	20.5	1.2	7.2	0.0	0.1
1986	84.1	49.3	13.2	2.5	10.7	2.3	4.9	0.8	7.2	0.0	0.1
1985	93.1	33.0	18.7	7.7	5.6	1.4	29.4	1.4	4.6	0.0	0.3
1984	149.3	95.4	7.9	4.8	0.4	6.4	17.7	1.9	14.1	0.0	0.4

Table 24. The number of trawls per station in each month at Stations 7, 9, and 10 in each year

Year	Station	2	3	4	5	6	7	8	9	10	11	12
2018	7	0	0	1	2	2	2	2	1	0	0	0
2018	9	0	0	1	2	4	2	2	1	0	0	0
2018	10	0	0	1	2	2	2	1	1	0	0	0
2017	7	0	0	1	2	2	2	2	1	0	0	0
2017	9	0	0	1	2	2	2	2	1	0	0	0
2017	10	0	0	1	2	0	0	0	0	0	0	0
2016	7	0	0	1	2	2	2	2	1	0	0	0
2016	9	0	0	1	2	2	2	2	1	0	0	0
2016	10	0	0	1	2	1	0	0	0	0	0	0
2015	7	0	0	1	2	2	2	2	1	0	0	0
2015	9	0	0	1	2	2	2	2	2	0	0	0
2015	10	0	0	1	2	0	0	0	0	0	0	0
2014	7	0	0	1	2	2	2	2	1	0	0	0
2014	9	0	0	1	2	2	2	2	1	0	0	0
2014	10	0	0	1	2	2	0	0	0	0	0	0
2013	7	0	0	1	2	2	2	2	1	0	0	0
2013	9	0	0	1	2	2	2	2	1	0	0	0
2013	10	0	0	1	2	2	1	0	0	0	0	0
2012	7	0	0	1	2	2	2	2	1	0	0	0
2012	9	0	0	1	2	2	2	2	1	0	0	0
2012	10	0	0	1	2	2	0	0	0	0	0	0
2011	7	0	0	1	2	3	2	2	1	0	0	0
2011	9	0	0	1	2	3	2	2	1	0	0	0
2011	10	0	0	1	2	3	2	0	1	0	0	0
2010	7	0	0	1	1	2	2	2	1	0	0	0
2010	9	0	0	1	1	2	2	2	1	0	0	0
2010	10	0	0	1	1	2	2	0	0	0	0	0
2009	7	0	0	1	2	2	2	2	1	0	0	0
2009	9	0	0	1	3	2	2	2	1	0	0	0
2009	10	0	0	1	2	2	2	3	1	0	0	0
2008	7	0	0	1	2	2	2	2	1	0	0	0
2008	9	0	0	1	1	2	1	2	1	0	0	0
2008	10	0	0	1	2	2	2	2	1	0	0	0
2007	7	0	0	1	2	2	2	2	1	0	0	0

2007	9	0	0	1	2	2	2	2	1	0	0	0
2007	10	0	0	1	2	2	2	2	1	0	0	0
2006	7	0	0	1	2	2	2	2	1	0	0	0
2006	9	0	0	1	2	2	2	2	1	0	0	0
2006	10	0	0	1	2	2	1	2	0	0	0	0
2005	7	0	0	1	2	2	2	2	1	1	0	0
2005	9	0	0	1	2	2	2	2	1	1	0	0
2005	10	0	0	1	2	2	2	2	0	0	0	0
2004	7	0	0	0	1	2	2	2	1	0	0	0
2004	9	0	0	1	1	2	2	2	1	0	0	0
2004	10	0	0	0	1	2	2	1	1	0	0	0
2003	7	0	1	2	2	2	2	1	1	1	1	1
2003	9	0	1	2	2	2	2	1	1	1	1	1
2003	10	0	1	2	2	2	2	1	1	1	1	1
2002	7	0	1	2	2	2	2	2	2	1	1	1
2002	9	0	1	2	2	2	2	2	2	1	1	1
2002	10	0	0	2	2	2	2	2	2	1	1	1
2001	7	0	1	2	2	1	2	3	2	1	1	1
2001	9	0	1	2	1	1	2	3	2	1	1	1
2001	10	0	1	2	2	1	2	3	2	1	1	1
2000	7	0	1	2	2	3	2	2	2	1	1	1
2000	9	0	1	2	2	3	2	2	2	1	1	1
2000	10	0	1	2	2	3	2	3	2	1	1	1
1999	7	0	1	2	2	2	2	2	2	1	1	1
1999	9	0	1	2	2	2	2	2	2	1	1	1
1999	10	0	1	2	2	2	2	2	2	1	1	1
1998	7	0	1	2	2	2	2	2	2	1	1	1
1998	9	0	1	2	2	2	2	2	2	1	1	1
1998	10	0	1	2	2	2	2	2	2	1	1	1
1997	7	0	1	2	2	2	2	2	2	2	1	1
1997	9	0	1	2	2	2	2	2	2	2	1	1
1997	10	0	1	2	2	2	2	2	2	2	1	1
1996	7	0	2	2	2	2	2	1	2	1	1	1
1996	9	0	1	2	2	1	2	1	2	1	1	1
1996	10	0	1	2	1	2	2	1	2	1	1	1
1995	7	0	1	2	2	2	2	2	2	2	1	0
1995	9	0	1	2	2	2	2	2	2	3	1	0
1995	10	0	1	2	2	2	2	2	2	2	1	0
1994	7	0	1	1	1	2	2	0	2	2	1	0
1994	9	0	0	1	1	2	2	0	2	2	1	0
1994	10	0	1	1	1	2	2	0	2	2	1	0
1993	7	0	0	1	2	2	3	2	2	2	1	1

1993	9	0	1	1	2	2	3	2	2	2	1	1
1993	10	0	0	1	2	2	3	2	2	2	1	1
1992	7	0	1	1	1	1	1	1	1	1	1	1
1992	9	0	1	1	0	1	1	1	1	1	1	1
1992	10	0	1	1	1	1	1	1	1	1	1	1
1991	7	0	1	1	1	1	1	1	1	1	1	0
1991	9	0	1	1	1	1	1	1	1	1	1	0
1991	10	0	1	2	1	1	1	1	1	1	1	0
1990	7	0	1	1	1	1	1	1	1	1	0	0
1990	9	0	1	1	1	1	1	1	1	1	0	0
1990	10	0	1	1	2	1	1	1	1	1	0	0
1989	7	1	1	1	1	1	1	2	2	1	1	0
1989	9	1	1	1	1	1	1	2	2	1	1	0
1989	10	1	1	1	1	1	1	2	2	1	1	0
1988	7	0	1	1	1	2	2	2	2	1	1	0
1988	9	0	0	0	0	0	0	0	2	1	1	0
1988	10	0	1	1	1	2	2	2	2	1	1	0
1987	7	0	1	1	1	1	1	1	1	1	1	0
1987	10	0	1	1	1	1	1	1	1	1	0	0
1986	7	0	1	1	1	1	1	1	1	1	1	0
1986	9	1	0	0	0	0	0	0	0	0	0	0
1986	10	0	2	1	1	1	1	1	1	1	1	0
1985	7	0	0	1	1	1	0	1	1	2	1	0
1985	10	0	0	1	1	1	0	1	1	2	1	0
1984	7	0	1	2	4	2	4	2	5	5	2	1
1984	10	0	1	2	4	3	4	2	4	5	2	1

Table 25. Mean catch per trawl of adult and juvenile fishes in all months at each station.

Year	7	9	10
2018	199.7	41.8	88.6
2017	187.9	9.0	30.7
2016	224.3	10.1	35.8
2015	360.0	15.8	31.7
2014	103.2	16.9	70.4
2013	236.0	12.2	30.3
2012	225.4	62.1	42.6
2011	113.5	33.9	76.4
2010	616.7	38.7	7.3
2009	142.8	34.6	49.1
2008	49.8	118.7	89.9
2007	390.1	253.8	64.4
2006	40.7	68.1	7.8
2005	106.4	95.0	22.0
2004	740.5	41.9	28.9
2003	68.9	65.8	39.5
2002	88.8	55.2	70.9
2001	167.8	77.1	119.1
2000	95.1	52.1	42.5
1999	117.1	23.1	56.8
1998	88.2	22.3	78.2
1997	111.2	50.1	51.6
1996	73.9	13.8	31.5
1995	109.3	30.5	71.4
1994	144.9	32.0	60.7
1993	377.1	31.2	116.1
1992	155.5	29.0	70.2
1991	185.9	70.9	66.5
1990	76.5	102.8	62.0
1989	52.6	14.2	103.8
1988	154.8	19.2	98.5
1987	84.6	NA	136.9
1986	101.8	1.0	157.1
1985	123.0	NA	148.8
1984	220.6	NA	205.8

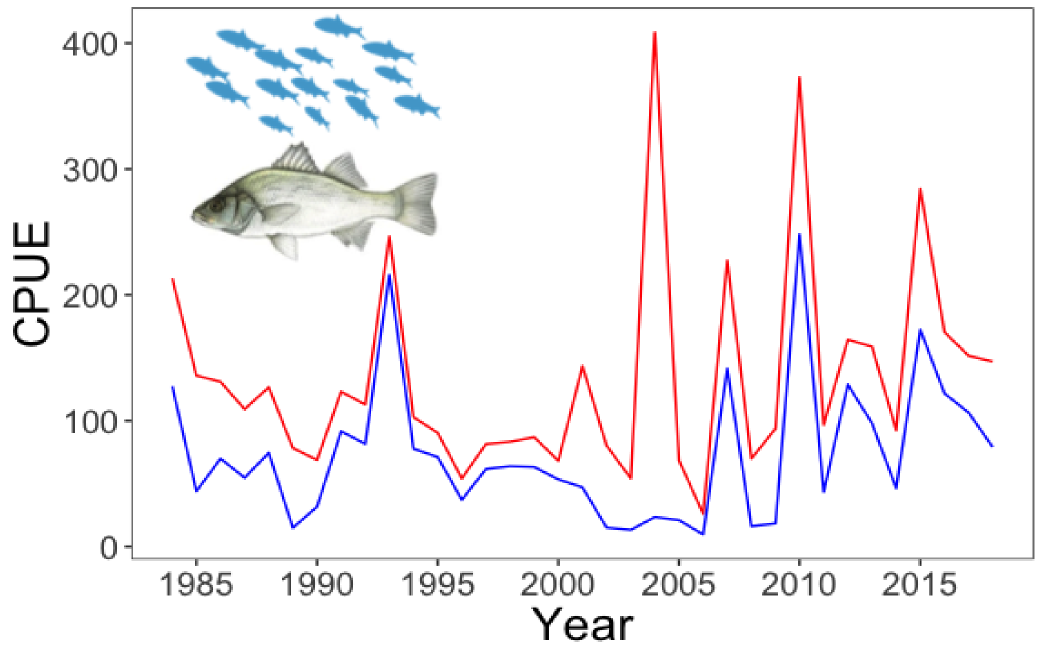


Figure 162. Trawls. Annual Averages. All Species (red) and *Morone americana* (blue). Cove Stations 7 and 10. 1984-2015.

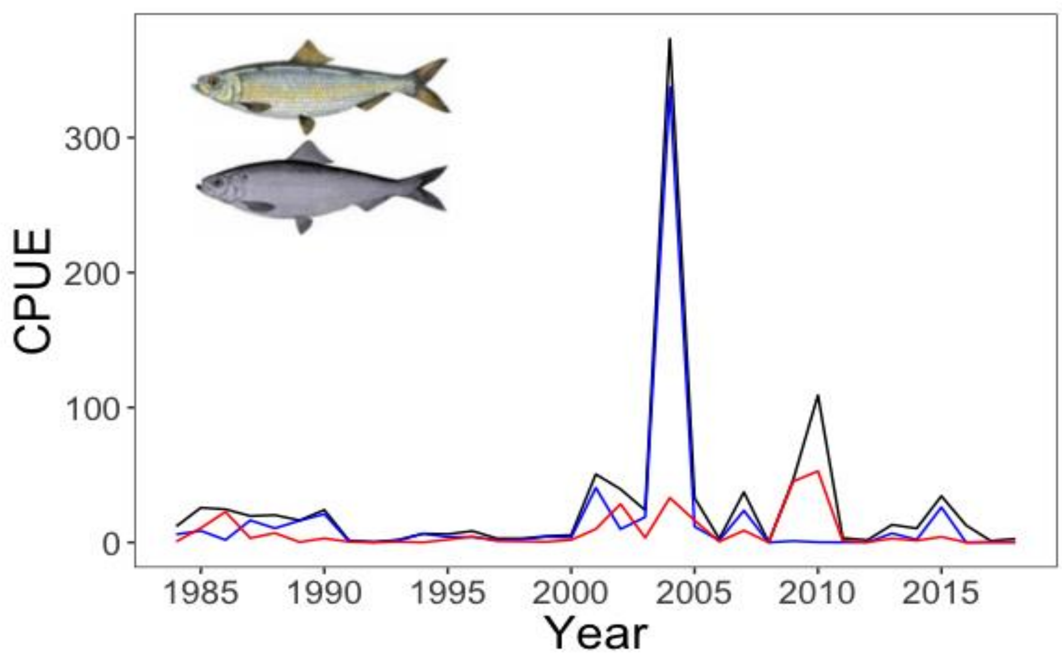


Figure 163. Trawls. Annual Averages. *Alosa aestivalis* (blue), *Alosa pseudoharengus* (red), and all combined *Alosa sp.* (black). Cove Stations 7 and 10.

The remaining component of the total catch (species other than White Perch) made up a moderate to large proportion of the catch until 1990; a relative small part of the catch between 1991 and 2000; and moderate to large proportion of the catch from 2001 to 2018. There was a high peak in catches other than White Perch in 2004, which was primarily due to exceptionally high catches of Blueback Herring (Figure 148; Figure 149).

The high peak in Blueback Herring catches in 2004 stands out in otherwise low catches (Figure 163). Generally, both herring species have been found in higher abundances since 2000 than in the decade before that. We included *Alosa sp*. (unidentified herring or shad) in Figure 163 in 2016, so that abundances of herring or shad are not missed simply because they could not be identified to the species level. This revealed the second highest peak in Alosines in 2010 not previously reported.

Mean catch at station 9 in 2018 was up again from low abundances since 2013, but still below the long-term mean (54; Table 22). The total catch at station 9 may be declining over time, and it would be interesting to pursue the research question whether and how blue catfish invasion has played a role in that. Blue catfish is regularly collected at station 9 the last 15 years, and hardly ever at the inner cove stations. Before 2017, Blue catfish was never collected at the inner cove station, but a few were collected there too in 2017 and 2018. The mean catch of all stations combined in 2018 is up again from last year and higher than the long-term mean of 103 (Table 23). The presence and location of SAV beds is partially responsible for the interannual variability. While SAV improves fish habitat, it decreases catchability, so trawl catches may increase when SAV cover is lacking.

Gizzard Shad catch rates in trawls in 2018 were low which contributes to a pattern of low abundance after a high peak in 1989 (Figure 164). Smaller peaks later occurred in 1991, 1997, 2008, and 2012, that were all an order of magnitude lower than the 1989 peak. Bay Anchovy catch rates in 2018 were low like they were in the last two years at inner cove stations, and trends in the data suggests decreasing trend over the length of the survey. They are primarily resident in more saline portions of the estuary, and display sporadic occurrence in tidal freshwater. Any decreases in Gunston Cove therefore do not indicate a declining trend in the abundance of this species overall.

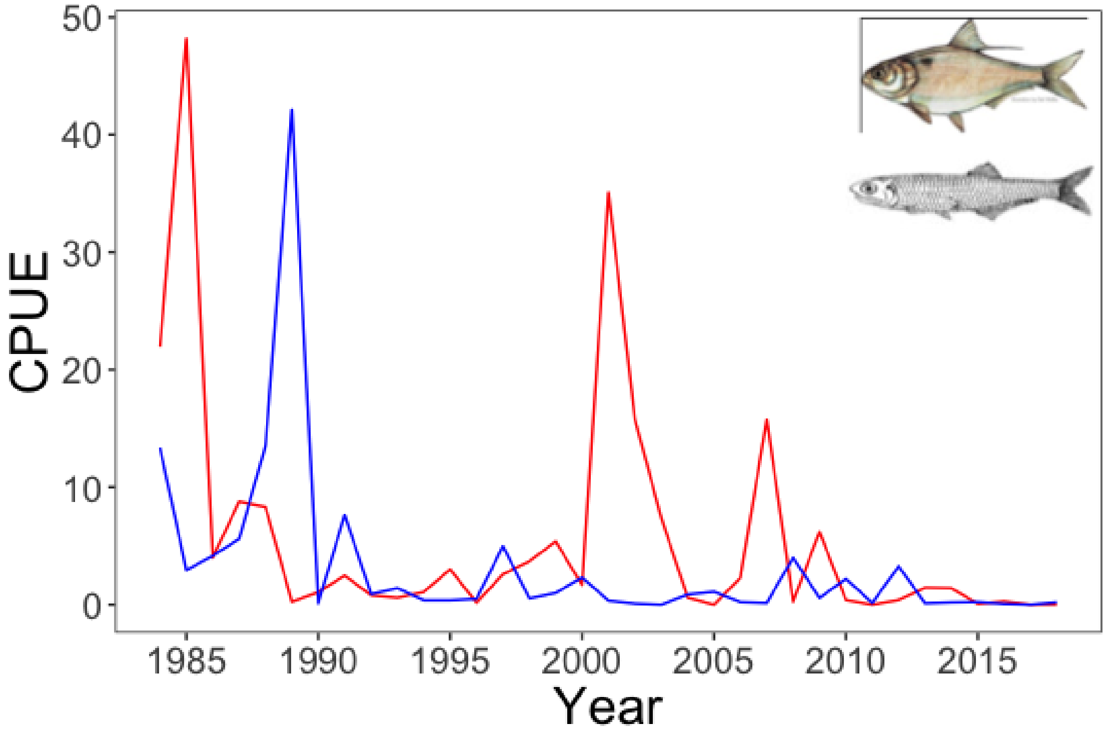


Figure 164. Trawls. Annual Averages. Cove Stations 7 and 10. *Dorosoma cepedianum* (blue) and *Anchoa mitchilli* (red).

Spottail Shiner and sunfishes have been consistently collected in the majority of all trawl and seine samples (Figure 165). An increasing trend has been observed for Spottail Shiner since the beginning of the survey. In recent years (since 2000), a more sharply increasing pattern is seen in the midst of high variability, with high numbers in 2007, 2011, 2013, and 2015 (Figure 165). We collected an unprecedented high number of Spottail Shiner specimens in 2015. These individuals were mostly juveniles, indicating relatively high reproductive success as measured by this survey. 2018 had another peak again, but to a lower extent than 2015, and similar to the 2013 peak. The trends for sunfishes showed have a similar pattern of low abundances in previous years and high abundance after 2005. Other sunfish species than Bluegill and Pumpkinseed have been included in the trend, which better reveals the increases in sunfishes that also include Green Sunfish, Redbreast Sunfish, and hybrids. Peaks occurred in 2008, 2011, and 2017. Sunfishes are associated with SAV, so their trend seems closely aligned with the expansion of SAV in 2005, and a decrease in 2018 may be a result of the low SAV cover of 2018.

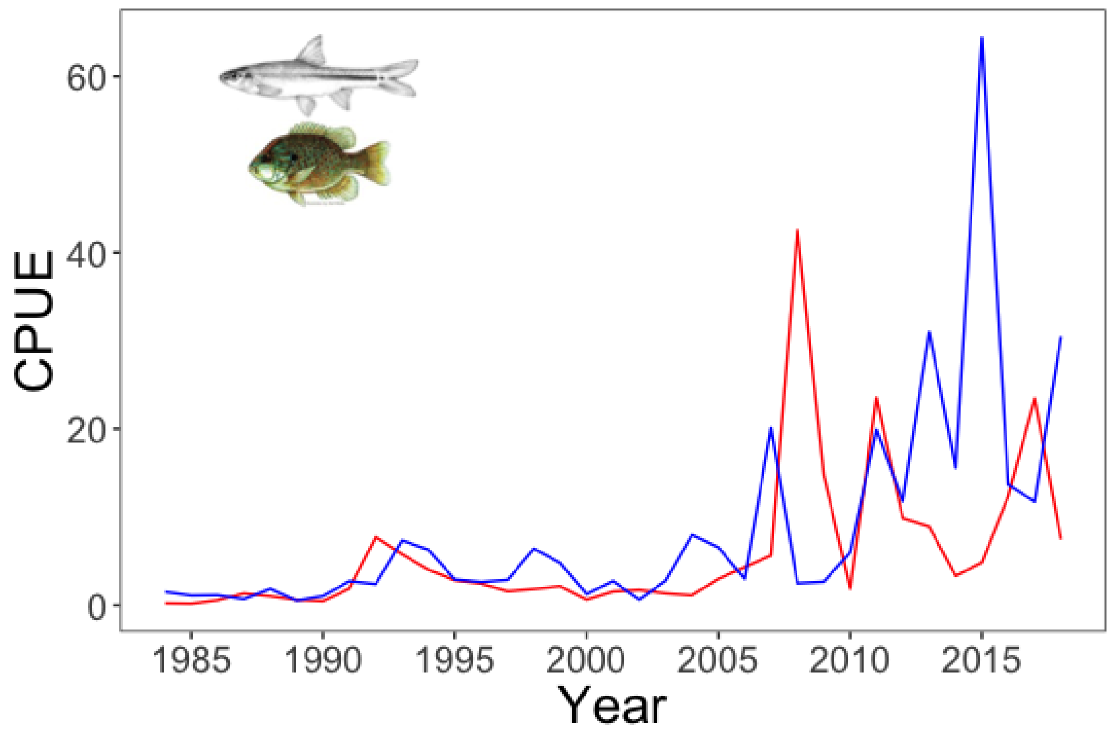


Figure 165. Trawls. Annual Averages. *Notropis hudsonius* (blue) and all *Lepomis sp.* (red). Cove Stations 7 and 10.

Sixteen Brown Bullhead specimens were captured in cove trawls in 2018, a slight uptick from 2017, but the trend still fits a continuing decline that has proceeded continuously since the start of the survey (Figure 166). Tessellated Darter was collected in unprecedented high numbers in trawl samples. The highest peak in abundance since the start of collections was seen in 2018. There were signs of slightly increasing abundances since 2005. The second highest peak in the period of record was observed in 2014, and didn't decrease much since then (Figure 167). Still, 2018 abundances are an order of magnitude higher than the last few years.

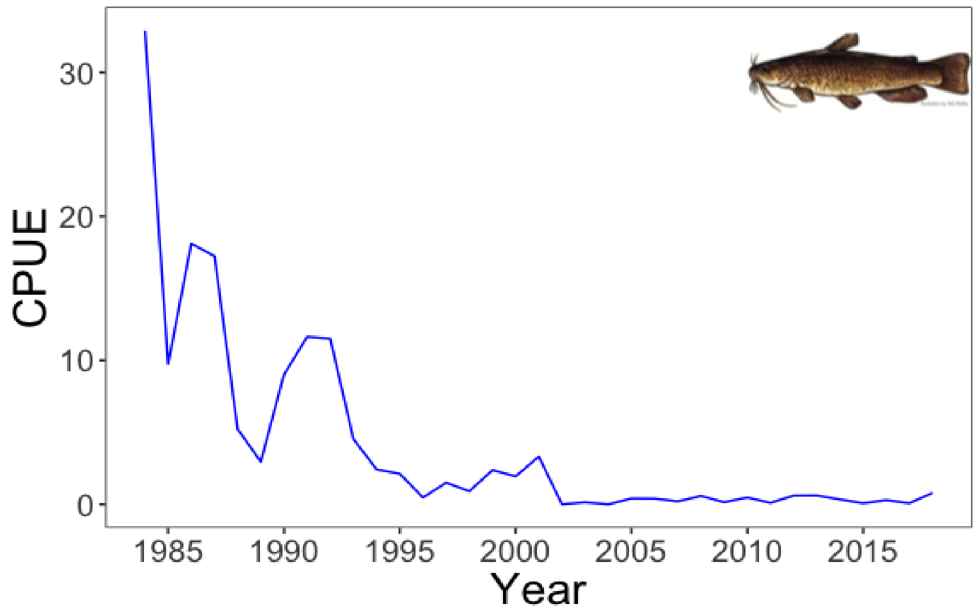


Figure 166. Annual Averages. *Ameiurus nebulosus*. Cove Stations 7 and 10.

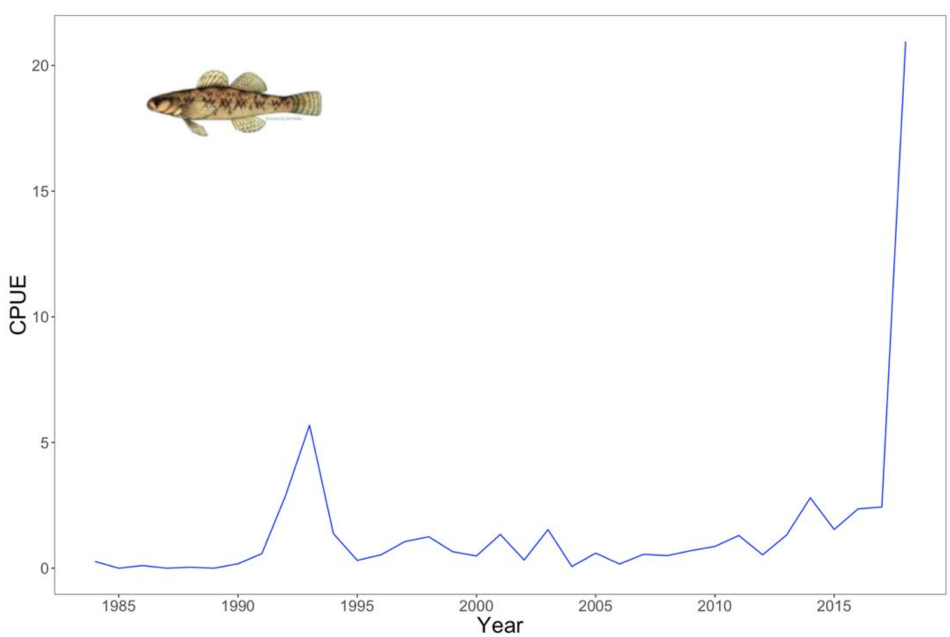


Figure 167. Trawls. Annual Averages of *Etheostoma olmstedi*. Cove stations 7 and 10.

At the river channel station (station 9), catches in 2018 were slightly higher than the last five years (Figure 168). As in the inner cove, much of the variation at station 9 is directly attributable to the catch of White Perch. Increases in Blue Catfish catch resulted in a higher increase in total catch than White Perch catch (Figure 154).

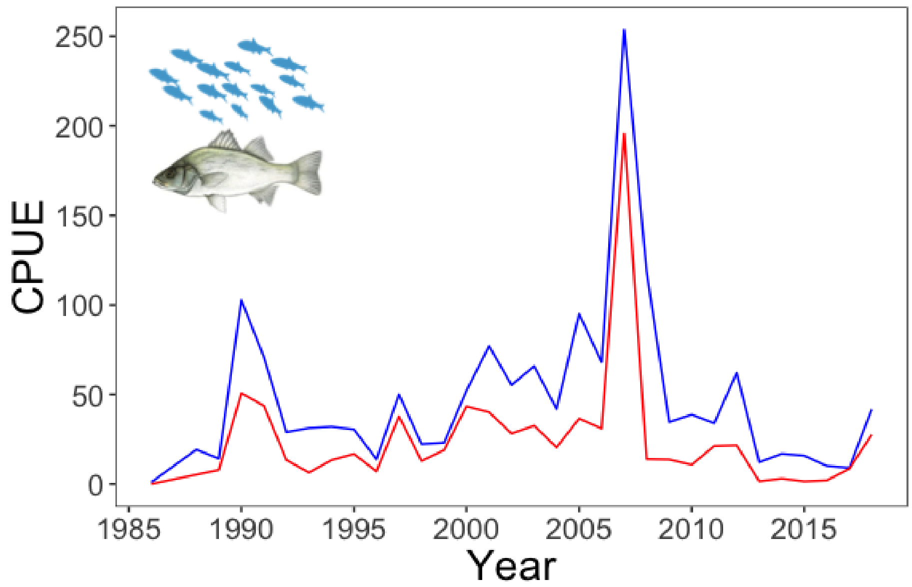


Figure 168. Trawls. Annual averages. River Station (9). Total catch (blue) and *Morone americana* (red).

Since 1988 when station 9 was incorporated as part of the survey, Bay Anchovy, Spottail Shiner, and American Eel have occurred sporadically at station 9 (Figure 169). We find high abundance of Bay Anchovy once every 5 years or so, with one very distinct peak in 2008. Spottail Shiner is found in low numbers every year at station 9, while American Eel has been rare since 1994.

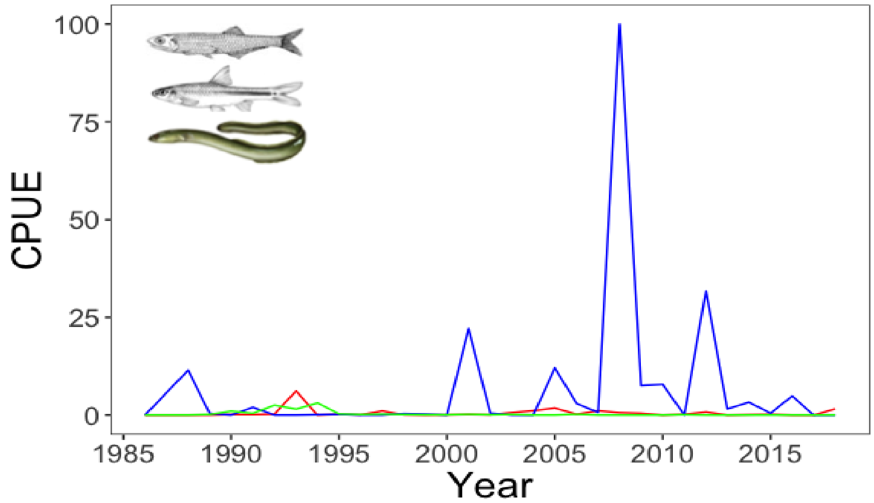


Figure 169. Trawls. Annual Averages. River Station (9). *Anchoa mitchilli* (Blue), *Notropis hudsonius* (red), and *Anguilla rostrata* (green).

Catch rates for native catfish species have been variable and low at station 9 since 2007 (Figure 170), with only a small peak from Channel Catfish in 2011. While no Channel Catfish was observed in 2018, ten White Bullhead and eight Brown Bullhead were collected in station 9 in 2018. While it is good to see that especially White Bullhead, a species that has not been collected at station 9 anymore for years, has not been completely extirpated, these numbers do not reverse the long-term mean trends identifying a decline in native catfishes. A species that warrants close attention is the invasive Blue Catfish, which was positively identified on the survey in 2001 and has been captured in high numbers relative to White Bullhead, Channel Catfish and Brown Bullhead ever since (Figure 170). Since Blue Catfish occupy the same niche, but can grow to larger sizes, it generally outcompetes the native catfish population (Schloesser et al., 2011). Blue Catfish established itself in 2001 with relatively high numbers, but the trend has remained flat since then (Figure 170). The system may have reached a new stable state that includes Blue Catfish in high numbers, and other catfishes in low numbers. Continued monitoring in the growth of this population is warranted. Of note is that we are not capturing very large specimens with the otter trawl, and very large Blue Catfishes have been reported in this area.

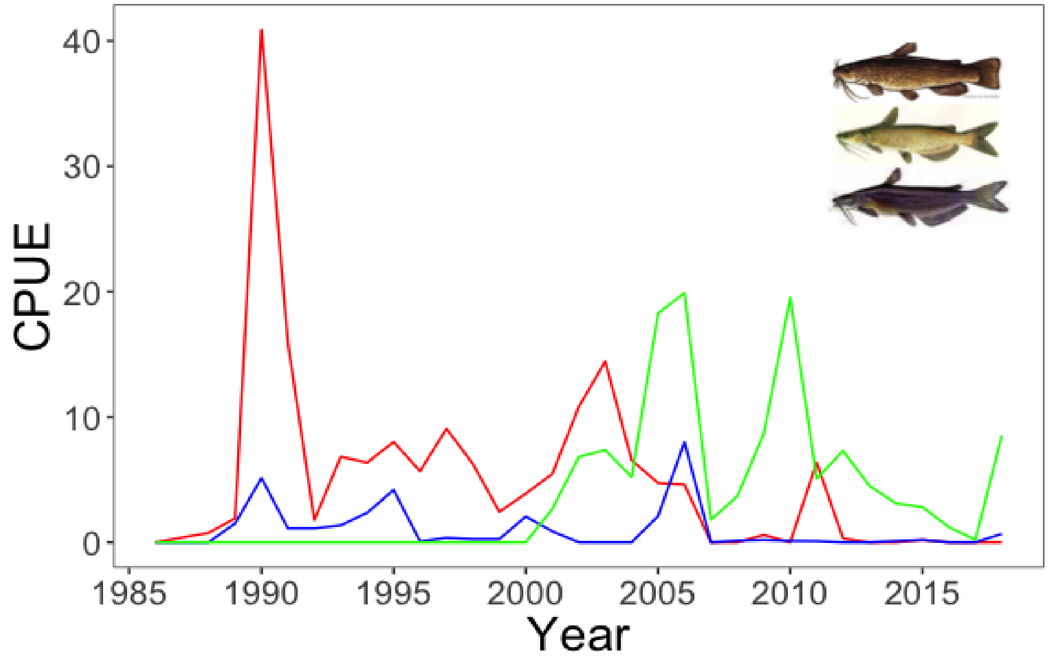


Figure 170. Trawls. Annual Averages. River Station (9). *Ameiurus nebulosus* (blue), *Ictalurus punctatus* (red), and *Ictalurus furcatus* (green).

Station 9 generally represents low catch rates for the demersal species Tessellated Darter and (Figure 171). In 2018 however, while not unprecedented as in the cove, the mainstem saw a peak in Tessellated Darter abundance. No Hogchokers were collected in 2018, which is same as last year.

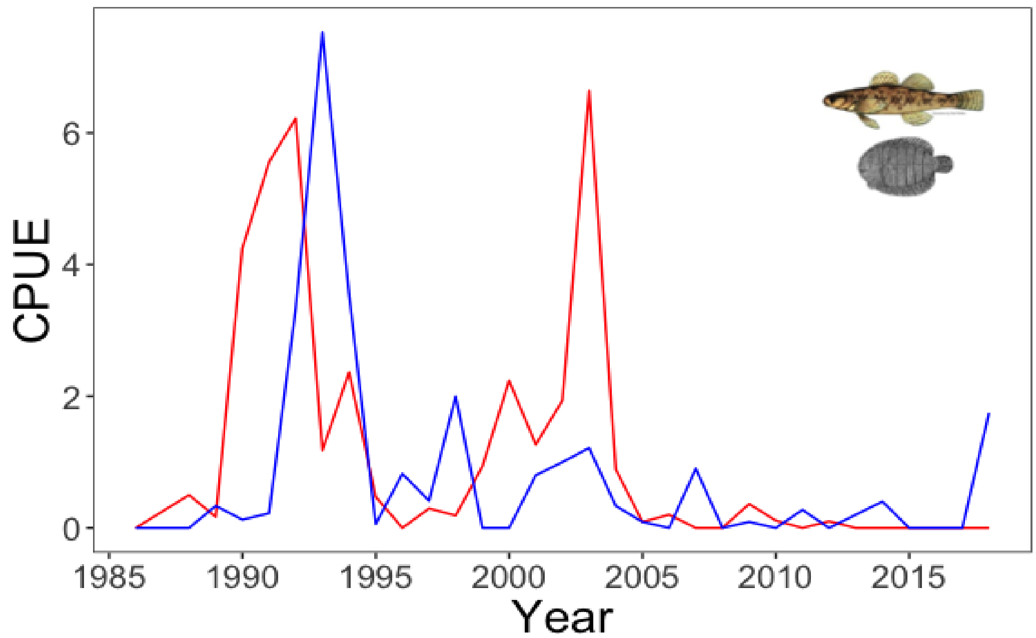


Figure 171. Trawls. Annual Averages. *Etheostoma olmstedi* (blue) and *Trinectes maculatus* (red). River Station (9).

Seines nets

Overall Patterns

Long-term trend of seine catches shows a stable pattern of catches amidst inter-annual variability (Table 26, Figures 172). The overall pattern shows a very slight increase in catches over the course of the survey. Of the three most abundant years high catches were due to a high abundance of Alosines those years: 1994 and 2004 were driven primarily by large catches of Alewife, whereas high catch rates in 1991 were a result of high catch rates of Blueback Herring (Table 26). The number of seine tows over the period of record is shown in Table 24.

Table 26. Mean Catch per Seine of Selected Adult and Juvenile Fishes at all Stations and all Months. 1985-2018.

Year	All Species	White Perch	Banded Killifish	Blueback Herring	Alewife	All Alosa Spp	Spottail Shiner	Inland Silverside
2018	118.5	4.5	50.5	0.0	0.0	46.4	2.3	1.8
2017	100.9	9.2	57.9	0.0	0.3	0.9	2.0	14.9
2016	114.3	11.6	64.5	0.0	0.0	6.9	1.2	8.1
2015	171.2	33.1	76.1	0.5	0.4	17.1	5.2	4.7
2014	169.5	11.9	121.4	3.5	0.1	8.3	4.1	4.1
2013	117.4	8.3	92.6	0.1	0.2	2.1	0.4	0.7
2012	186.0	5.4	131.7	0.0	2.1	4.5	6.1	12.4
2011	140.8	31.0	76.3	0.0	1.3	2.0	2.4	1.5
2010	249.4	15.8	175.6	0.1	1.6	4.6	1.6	1.3
2009	186.5	18.7	67.4	0.3	0.2	1.4	3.6	6.9
2008	196.5	15.4	51.8	0.3	0.1	2.5	3.0	14.9
2007	130.4	15.0	40.6	6.7	2.2	17.6	3.4	2.3
2006	165.3	7.6	113.7	3.2	0.4	6.2	3.6	16.2
2005	202.0	32.0	125.2	1.0	5.4	7.2	9.7	5.6
2004	304.5	45.3	99.1	11.1	73.8	85.2	38.1	9.5
2003	100.6	7.5	42.9	2.3	2.8	7.5	7.3	4.8
2002	164.4	23.1	89.7	0.0	2.2	3.2	12.5	14.4
2001	134.0	30.2	54.6	0.0	4.9	5.6	14.3	7.6
2000	152.2	28.9	26.2	1.7	6.0	7.7	23.5	50.1
1999	108.1	18.3	19.0	14.4	0.4	14.8	12.3	25.0
1998	111.6	22.2	31.6	2.1	1.0	3.1	25.9	8.7
1997	96.8	12.8	34.0	17.6	1.5	19.0	4.5	13.8
1996	103.6	29.1	18.2	15.4	5.4	22.2	11.8	4.7
1995	88.8	26.1	16.3	2.1	2.8	5.0	5.8	12.5
1994	294.9	15.6	13.9	0.0	250.2	250.2	7.2	0.1
1993	73.6	13.4	26.1	3.2	1.3	4.5	8.5	9.1
1992	154.5	43.6	35.8	39.2	0.0	39.2	9.0	5.8
1991	204.9	30.2	45.1	66.2	0.2	66.4	17.5	6.0
1990	118.7	41.2	27.8	7.4	1.1	8.5	9.0	4.0
1989	130.8	39.9	25.8	1.8	0.5	2.2	8.1	1.9
1988	146.5	42.1	48.6	2.2	0.3	2.6	9.3	6.2
1987	108.9	36.7	31.9	0.0	0.0	0.0	8.0	11.6
1986	130.5	55.1	15.3	0.2	0.8	1.3	6.4	19.9
1985	120.2	36.8	11.7	0.0	0.1	0.2	13.2	29.3

Table 27. The number of seines in each month at Station 4, 4B, 6, and 11 in each year. 1985-2018.

Year	Station	1	2	3	4	5	6	7	8	9	10	11	12
2018	4	0	0	0	1	2	2	2	2	1	0	0	0
2018	6	0	0	0	1	2	2	2	2	1	0	0	0
2018	11	0	0	0	1	2	2	2	2	1	0	0	0
2018	4B	0	0	0	1	2	2	2	2	1	0	0	0
2017	4	0	0	0	1	2	2	0	0	0	0	0	0
2017	6	0	0	0	1	2	2	2	2	1	0	0	0
2017	11	0	0	0	1	2	2	2	2	1	0	0	0
2017	4B	0	0	0	1	2	2	2	2	1	0	0	0
2016	4	0	0	0	1	2	1	0	0	0	0	0	0
2016	6	0	0	0	1	2	2	2	2	1	0	0	0
2016	11	0	0	0	1	2	2	2	2	1	0	0	0
2016	4B	0	0	0	1	2	2	2	2	1	0	0	0
2015	4	0	0	0	1	2	2	0	0	0	0	0	0
2015	6	0	0	0	1	2	2	2	2	1	0	0	0
2015	11	0	0	0	1	2	2	2	2	1	0	0	0
2015	4B	0	0	0	1	2	2	2	2	1	0	0	0
2014	4	0	0	0	1	2	2	1	1	0	0	0	0
2014	6	0	0	0	1	2	2	2	2	1	0	0	0
2014	11	0	0	0	1	2	2	2	2	1	0	0	0
2014	4B	0	0	0	1	2	2	2	2	1	0	0	0
2013	4	0	0	0	1	2	2	2	1	0	0	0	0
2013	6	0	0	0	1	2	2	2	2	1	0	0	0
2013	11	0	0	0	1	2	2	2	2	1	0	0	0
2013	4B	0	0	0	1	2	2	2	2	1	0	0	0
2012	4	0	0	0	1	2	2	1	0	0	0	0	0
2012	6	0	0	0	1	2	2	2	2	1	0	0	0
2012	11	0	0	0	1	2	2	2	2	1	0	0	0
2012	4B	0	0	0	1	2	2	2	2	1	0	0	0
2011	4	0	0	0	1	3	3	3	2	1	0	0	0
2011	6	0	0	0	1	2	3	2	2	0	1	0	0
2011	11	0	0	0	1	2	3	2	2	1	0	0	0
2011	4B	0	0	0	1	2	3	2	2	1	0	0	0
2010	4	0	0	0	1	1	2	2	2	1	0	0	0
2010	6	0	0	0	1	1	2	2	2	1	0	0	0
2010	11	0	0	0	1	1	2	2	2	1	0	0	0
2010	4B	0	0	0	1	1	2	2	2	1	0	0	0
2009	4	0	0	0	1	2	2	2	2	1	0	0	0
2009	6	0	0	0	1	2	2	2	2	1	0	0	0

2009	11	0	0	0	1	2	2	2	2	1	0	0	0
2009	4B	0	0	0	1	2	2	2	2	1	0	0	0
2008	4	0	0	0	1	2	2	2	2	1	0	0	0
2008	6	0	0	0	1	2	2	2	2	1	0	0	0
2008	11	0	0	0	1	2	2	2	2	1	0	0	0
2008	4B	0	0	0	1	2	2	2	2	1	0	0	0
2007	4	0	0	0	1	2	1	2	2	1	0	0	0
2007	6	0	0	0	1	2	1	2	2	1	0	0	0
2007	11	0	0	0	1	2	1	2	2	1	0	0	0
2007	4B	0	0	0	0	0	0	2	2	1	0	0	0
2006	4	0	0	0	1	2	1	0	0	1	0	0	0
2006	6	0	0	0	1	2	2	2	0	0	0	0	0
2006	11	0	0	0	1	2	2	2	2	1	0	0	0
2005	4	0	0	0	1	2	2	2	1	0	0	0	0
2005	6	0	0	0	1	2	2	2	1	0	0	0	0
2005	11	0	0	0	1	2	2	2	2	1	1	0	0
2004	4	0	0	0	1	1	2	1	0	0	0	0	0
2004	6	0	0	0	1	1	2	0	0	0	0	0	0
2004	11	0	0	0	1	1	2	2	2	1	0	0	0
2003	4	0	0	1	2	2	2	2	2	1	1	1	1
2003	6	0	0	1	2	2	2	2	2	1	1	1	1
2003	11	0	0	1	2	2	2	2	2	1	1	1	1
2002	4	0	0	1	2	2	2	2	2	2	1	1	1
2002	6	0	0	1	2	2	2	2	2	2	1	1	1
2002	11	0	0	1	2	2	2	2	2	2	1	1	1
2001	4	0	0	1	2	2	1	2	3	2	1	1	1
2001	6	0	0	1	2	2	1	2	3	2	0	1	1
2001	11	0	0	1	2	2	1	2	3	2	1	1	1
2000	4	0	0	1	2	2	3	2	2	2	1	1	1
2000	6	0	0	1	2	2	3	2	2	2	1	1	1
2000	11	0	0	1	2	2	3	1	2	0	1	1	2
1999	4	0	0	1	2	2	2	2	2	2	0	1	1
1999	6	0	0	1	1	2	1	2	2	2	1	1	1
1999	11	0	0	1	2	2	2	2	2	2	1	1	1
1998	4	0	0	1	2	2	2	2	2	2	1	1	1
1998	6	0	0	1	2	2	2	2	2	2	1	1	1
1998	11	0	0	1	2	2	2	2	2	2	1	1	1
1997	4	0	0	1	2	2	2	2	2	2	2	1	1
1997	6	0	0	1	2	2	2	2	2	2	2	1	1
1997	11	0	0	1	3	4	2	2	2	2	2	1	1
1996	4	0	0	1	2	2	2	2	1	2	1	1	1
1996	6	0	0	1	2	2	2	2	1	2	1	1	1

1996	11	0	0	1	2	2	2	2	1	2	1	1	1
1995	4	0	0	1	1	2	2	2	2	2	2	1	0
1995	6	0	0	1	2	2	2	2	2	2	2	1	0
1995	11	0	0	1	2	2	1	2	2	3	2	1	0
1994	4	0	0	0	0	1	1	0	0	1	1	0	0
1994	6	0	0	3	0	1	1	0	0	1	1	0	0
1994	11	0	0	3	0	1	1	0	0	1	1	0	0
1993	4	0	0	1	2	2	1	3	2	0	1	1	1
1993	6	0	0	1	1	2	1	3	2	0	1	1	1
1993	11	0	0	1	2	2	1	3	2	0	1	1	1
1992	4	0	0	1	1	1	1	1	1	1	1	1	0
1992	6	0	0	1	1	1	1	1	1	1	1	1	0
1992	11	0	0	0	1	1	1	1	1	1	1	1	0
1991	4	0	0	1	1	1	1	1	1	1	1	1	0
1991	6	0	0	1	1	1	1	1	2	1	1	2	0
1991	11	0	0	1	1	1	1	1	1	1	1	1	0
1990	4	0	0	1	1	1	1	1	1	1	0	0	0
1990	6	0	0	1	1	1	1	1	1	1	0	0	0
1990	11	0	0	1	1	1	1	1	1	1	0	0	0
1989	4	0	0	1	1	1	1	1	1	1	1	1	0
1989	6	0	0	1	1	1	1	1	1	1	1	1	0
1989	11	0	0	1	1	1	1	1	1	1	1	1	0
1988	4	0	0	1	1	0	2	2	1	1	1	1	0
1988	6	0	0	1	1	1	2	2	2	1	1	1	0
1988	11	0	0	1	1	1	2	2	2	1	1	1	0
1987	4	0	0	1	1	0	1	1	0	0	1	1	0
1987	6	0	0	1	1	0	1	1	0	0	1	0	0
1987	11	0	0	1	1	0	1	1	0	0	1	1	0
1986	4	0	1	0	1	0	1	0	0	3	4	0	0
1986	6	1	1	0	1	1	1	0	0	5	2	1	0
1986	11	2	1	0	1	1	1	0	2	4	4	1	0
1985	4	0	0	0	1	0	0	0	1	2	3	4	0
1985	6	0	0	0	0	0	0	0	1	3	3	4	0
1985	11	0	0	0	0	0	0	0	2	3	3	4	0

Overall, Banded Killifish and White Perch have been the dominant species in seine samples throughout the survey. In 2018, the general trend of decreasing White Perch catches and increasing Banded Killifish catches over the period of record continued (Figure 173 and 174). The decrease in White Perch seen in seine catches is indication of the shifted ecosystem state to an SAV dominated system, since Banded Killifish prefers SAV habitat, while White Perch prefers open water. The decreasing trend in white Perch, and increasing trend in Banded Killifish, seems to be leveling out, and a new stable state in the relative contribution of these two species may have been reached. Subsequent years will determine whether this is indeed the case.

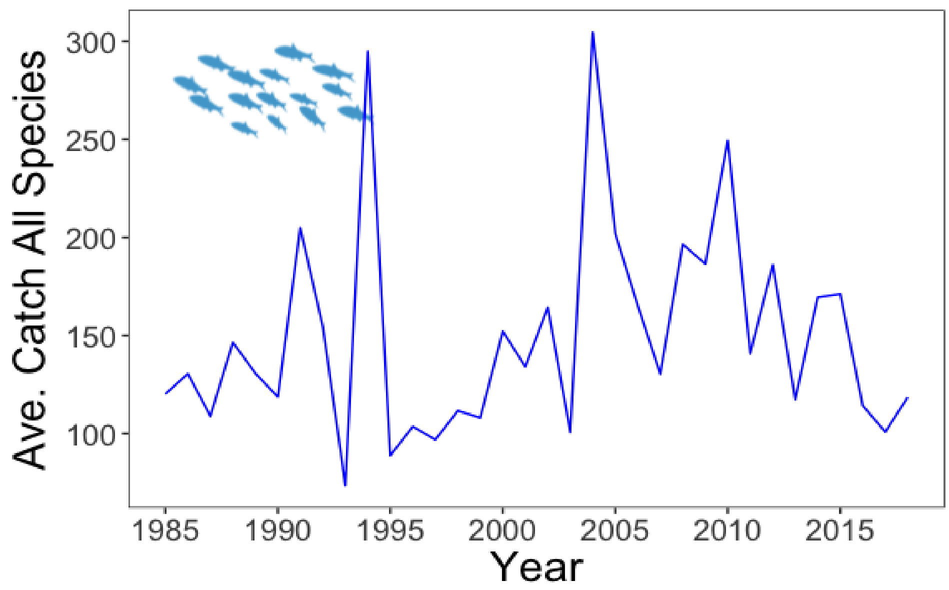


Figure 173. Seines. Annual Average over Stations 4, 4A, 6, and 11. All Species. 1985-2018.

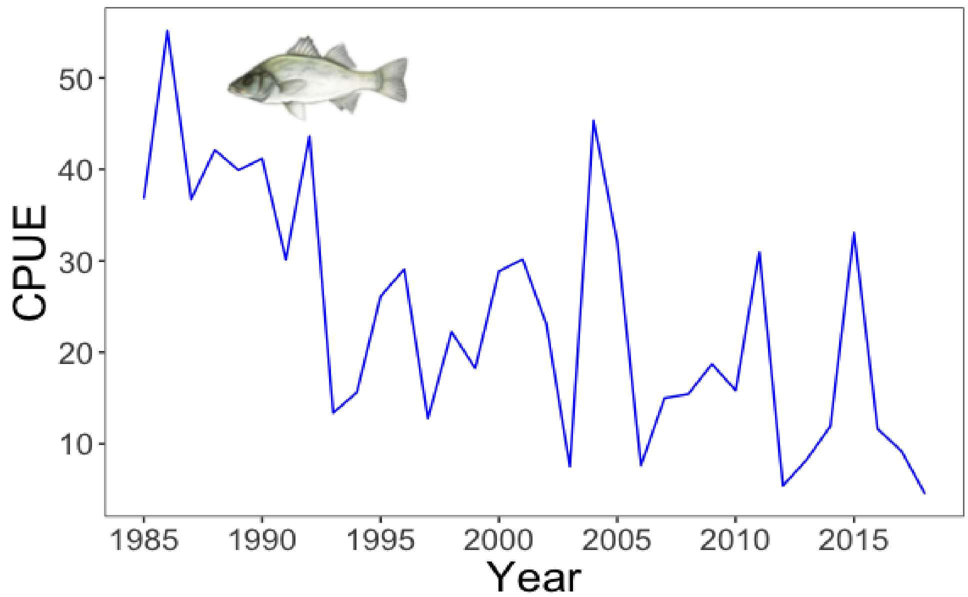


Figure 174. Seines. Annual Average Stations 4, 4A, 6, and 11. *Morone americana*. 1985-2018.

Over the course of the survey mean annual seine catch rates of White Perch have exhibited a gradual decline (Figures 173). An important factor is the pronounced increase in SAV, which until 2012 was not effectively sampled and could potentially represent a significant alternative habitat for White Perch.

Long-term trends in mean annual catch rates for the two dominant species in seine hauls have exhibited a negative association (r=-0.427) over the course of the survey. White Perch mean catches have declined steadily since the beginning of the survey, while Banded Killifish numbers have increased since the start of the survey, and experienced a prominent increase since 1999 (Figure 174).

The relative success of Banded Killifish is coincidentally (rather than functionally related) to declines in White Perch as these species show very little overlap in ecological and life history characteristics. Instead, as mentioned above, prominent increases in mean catch rates of Banded Killifish are associated with development of SAV in the cove since 2000. The SAV provides refuge for Banded Killifish adults and juveniles and may enhance feeding opportunities with epifaunal prey items. Essentially, the habitat of White Perch in Gunston Cove has decreased, while the habitat of Banded Killifish has increased. However, White Perch does reside in SAV covered areas as well, just in lower numbers.

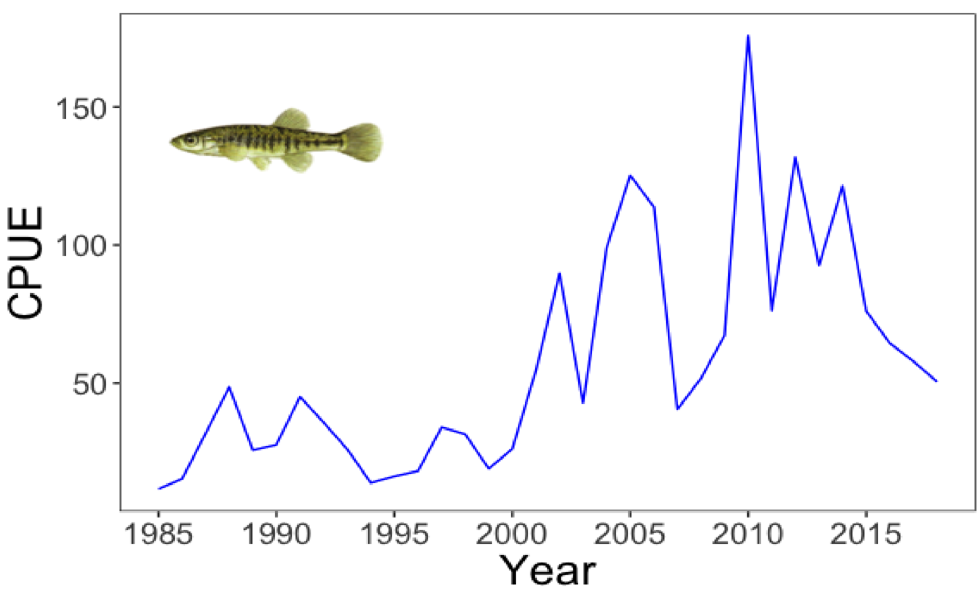


Figure 174. Seines. Annual Average Stations 4, 4A, 6, and 11. *Fundulus diaphanus*. 1985-2018.

Mean annual catch rates for river herring (Alewife and Blueback Herring) have exhibited sporadic peaks related to the capture of a large schools of fish (exceeding 200 for Alewife and approaching 100 individuals for Blueback Herring) in single hauls (Figure 175). Typically, less than 10 of either species were captured in a single sample. Though very variable, long-term trends indicate a decline in overall catches of Alewife and Blueback Herring. These species are both listed as species of concern and have experienced declines throughout the Chesapeake Bay watershed. The moratorium on river herring since January 2012 has been put in place as an aid in the recovery. If successful, the moratorium (on fishing) may results in an increase in river herring over time in future years. We added the category 'all *Alosa sp*.' to figure 161 in 2016 because a large portion of the Alosines cannot be identified to the species level. That revealed that Alosine abundances have been slightly higher since 2005 then just based on Alewife and Blueback Herring findings. For example, relatively high peaks in Alosines have been found in 2007, 2010, 2015, and now again in 2018. Abundances are not sufficiently high that the stocks can be considered recovered. Continued monitoring will be key in determining the success of the moratorium. The high numbers of spawning adult river herring in 2015 in Pohick Creek, as described in the 2015 Anadromous Report, could signal the start of the recovery of these species. After lower abundances in 2016 and 2017, 2018 showed another peak for Alewife, indicating the large cohort of 2015 successfully returned to spawn (see Anadromous Report).

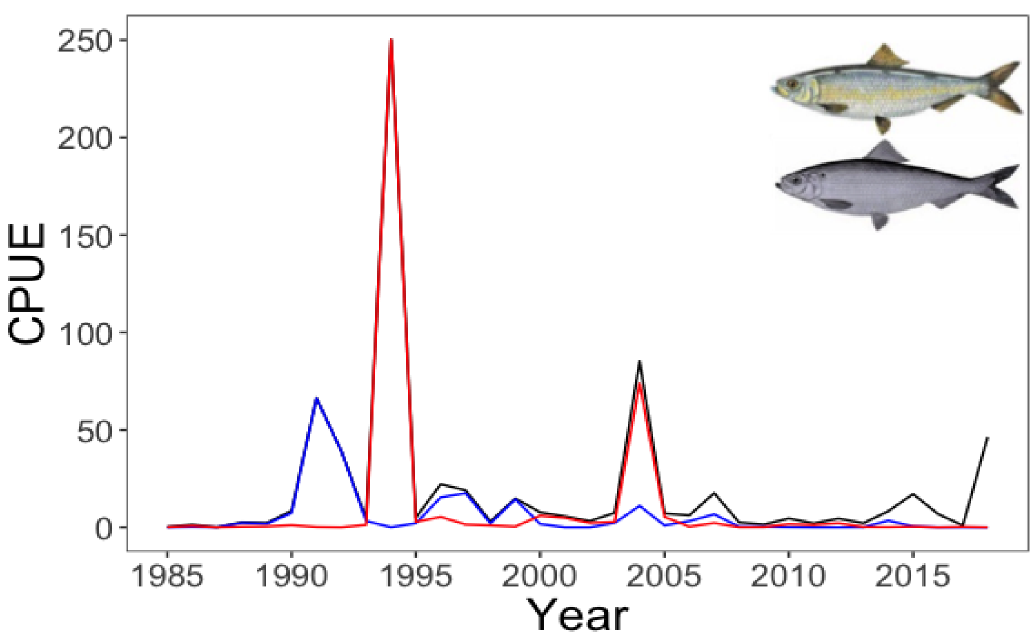


Figure 175. Seines. Annual Average over 4, 4A, 6, and 11 Stations. *Alosa aestivalis* (blue), *A. pseudoharengus* (red), and all *Alosa sp.* (black; *A. aestivalis*, *A. pseudoharengus*, *A. mediocris*, *A. sapidissima*, and unidentified Herring and Shad species). 1985-2018.

Owing to their affinity for marginal and littoral zone habitats, Spottail Shiner and Inland Silverside are consistently captured at moderate abundances throughout the course of the survey (Figure 176). Highest peaks occurred in 1999 and 2004 for Inland Silverside and Spottail Shiner respectively (Figure 176). After these high peaks, Inland Silverside remains relatively abundant with small peaks in 2006, 2008, 2012, and 2017, while Spottail Shiner decreases. Like previous years, Inland Silverside had relatively high abundance in the fyke nets, and was the third most abundant species in fyke nets in 2018. While the fyke nets did capture a high proportion of Spottail Shiner in 2014, none were collected in 2018. With the variable record within the SAV-beds as represented by the fyke net catches, similar to the record of trawl catches, these species do not seem to have particularly concentrated in SAV beds, but rather have remained moderately abundant throughout the Cove and the survey when all gear is considered.

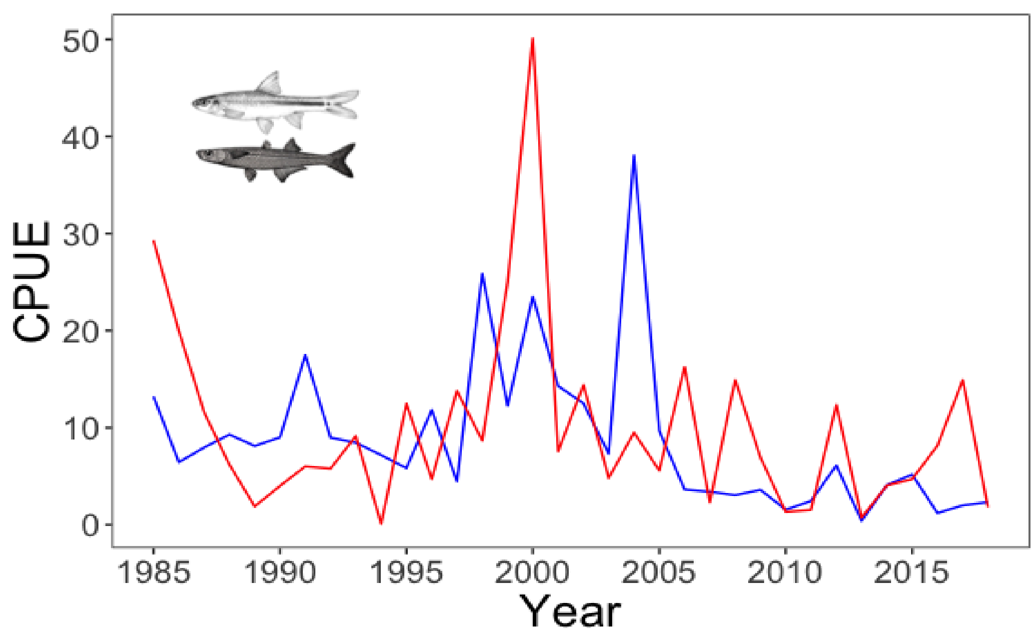


Figure 176. Seines. Annual Average over 4, 4A, 6, and 11 Stations. *Notropis hudsonius* (blue) and *Menidia beryllina* (red). 1985-2018.

Fyke nets

Overall Patterns

In 2012, fyke nets were added to the sampling gear near Station 4 (seine station where SAV interferes halfway during the sampling season) and Station 10 (trawl station where SAV interferes with sampling halfway during the sampling season) (Figure 177, Table 28). For the first three years of fyke net collections (2012-2014), White Perch was not among the dominant species in fyke nets. However, in 2015 White Perch was the second most dominant species in fyke net collections, and was present again in 2016 and 2017, indicating it is present within the SAV beds as well (Figure 178). Fyke nets efficiently sample SAV beds, and are usually dominated by SAV-associated species like Banded Killifish and sunfishes. The state shift of the ecosystem to a SAV dominated system has resulted in a shift in the nekton community from open-water species to SAV-associated species.

Fyke nets collected less specimens in 2018 than the previous year, resulting in the lowest abundance in fyke nets for the period of record (2012-2018; Table 29, Figure 177). Collections were dominated by sunfishes. Like previous years, the relative contribution of other species in fyke nets is different than in collections with trawl or seine nets. The fyke nets mainly represents SAV-associated species such as several species of sunfishes. Low abundance in 2018 seems associated with low SAV cover, as the fyke nets become relatively inefficient gear then due to their visibility. Because of the ability of fishes to avoid the nets, not only species that are associated with SAV decline in fyke net collections when SAV cover is low, such as sunfishes and banded killifish (179, 180, 183), but also species associated with open water, such as White Perch (Figure 178, 181, 182).

Table 28. The number of fykes in each month at Station Fyke 1 and Fyke 2 in each year. 2012-2018.

Year	Station	4	5	6	7	8	9
2018	Fyke1	1	2	2	2	2	1
2018	Fyke2	1	2	2	2	2	1
2017	Fyke1	0	2	2	2	2	1
2017	Fyke2	0	2	2	2	2	1
2016	Fyke1	1	2	2	2	2	1
2016	Fyke2	1	2	2	2	2	1
2015	Fyke1	1	2	1	2	2	1
2015	Fyke2	1	2	1	2	2	1
2014	Fyke1	1	2	2	2	2	1
2014	Fyke2	1	2	2	2	2	1
2013	Fyke1	0	2	2	2	2	1
2013	Fyke2	0	2	2	2	2	1
2012	Fyke1	0	0	1	2	2	1
2012	Fyke2	0	0	1	2	2	1

Table 26. Mean Catch per Fyke of Selected Adult and Juvenile Fishes at all Stations and all Months. 2012-2018.

Year	**All Species**	**Sunfish**	**Banded Killifish**	**Inland Silverside**	**Tessellated Darter**	**Brown Bullhead**	**Largemouth Bass**	**Goldfish**
2018	5.2	3.1	0.0	0.7	0.5	0.2	0.0	0.0
2017	66.4	38.3	11.1	10.8	0.1	0.1	0.2	1.5
2016	22.8	14.7	5.3	1.0	0.0	0.0	0.5	0.0
2015	36.6	6.4	25.3	1.1	0.1	0.0	0.0	0.3
2014	60.4	12.4	39.3	0.1	0.3	2.3	0.0	0.1
2013	25.3	6.1	16.8	0.7	0.1	0.0	0.0	0.2
2012	120.0	85.0	25.0	0.0	0.4	0.0	2.9	4.3

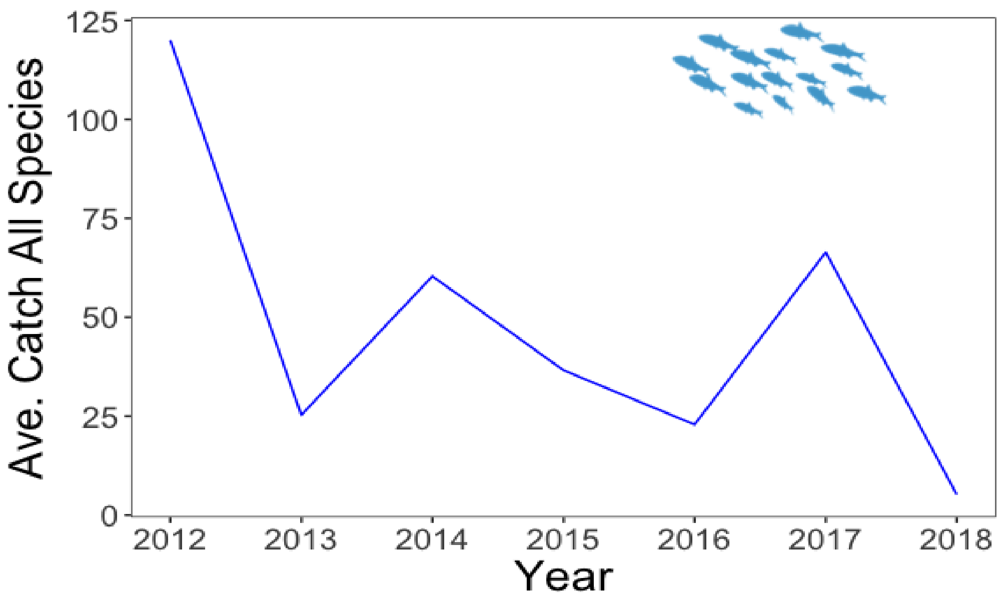


Figure 177. Fykes Annual Average over Stations Fyke 1 and Fyke 2. All Species. 2012-2018.

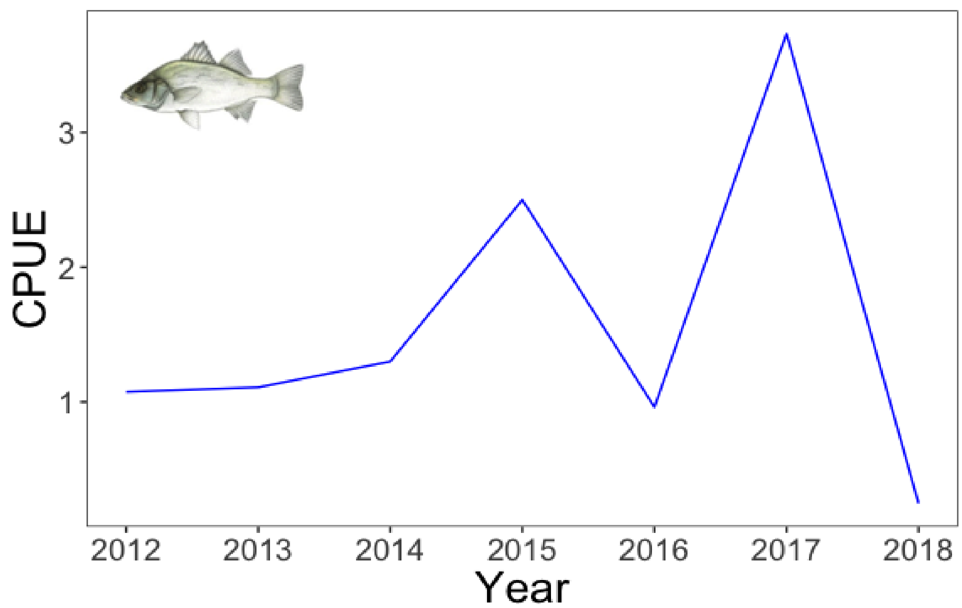


Figure 178. Fyke Annual Average Stations Fyke 1 and Fyke 2. *Morone americana*. 2012-2018.

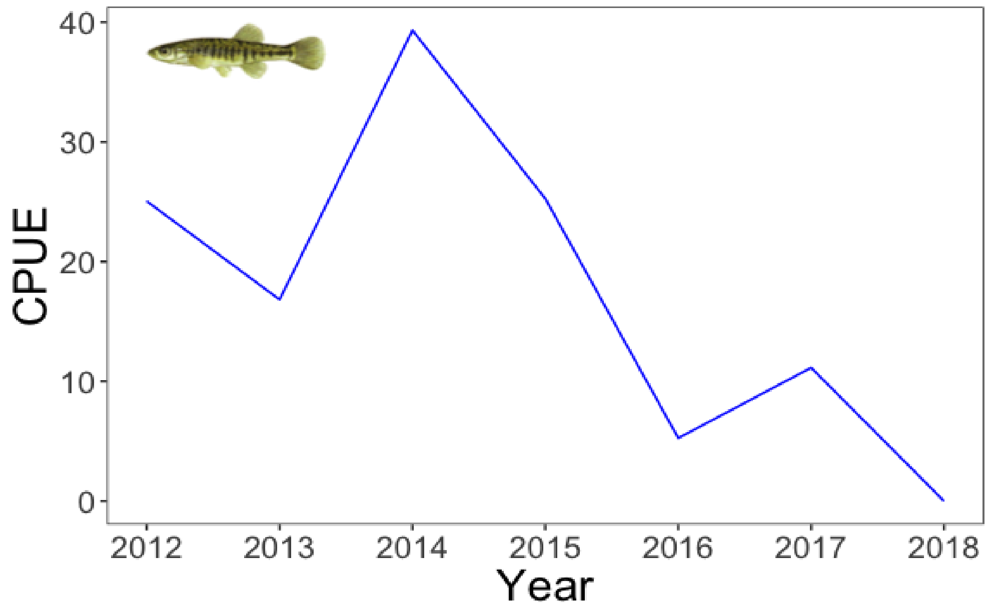


Figure 179. Fyke Annual Average Stations Fyke 1 and Fyke 2. *Fundulus diaphanus*. 2012-2018.

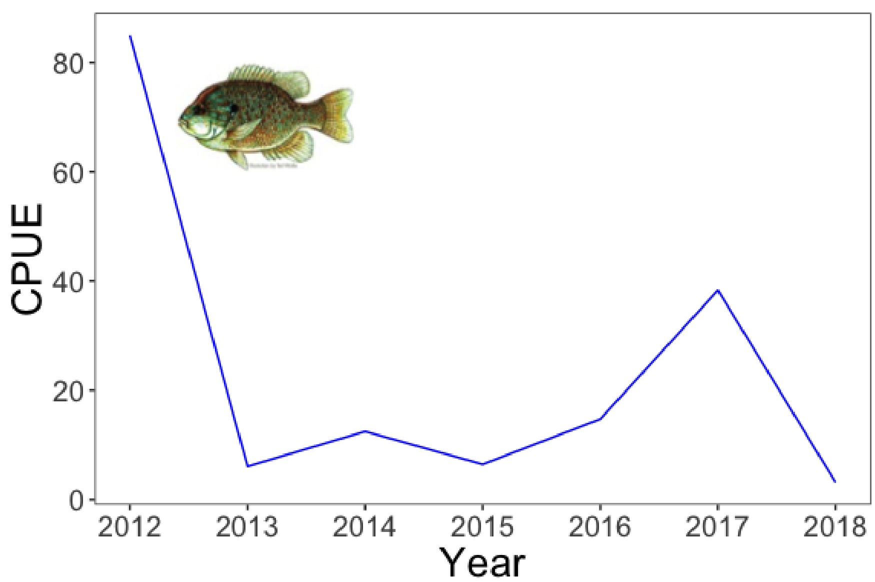


Figure 180. Fykes Annual Average over Fyke 1 and Fyke 2 Stations. All *Lepomis sp.* (blue). 2012-2018.

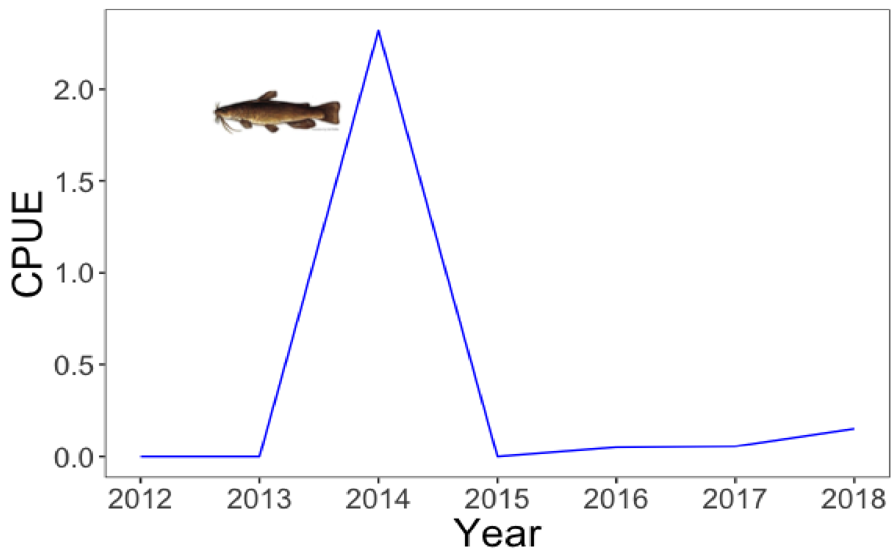


Figure 181. Fykes Annual Average over Fyke 1 and Fyke 2 Stations. *Ameiurus nebulosus* (blue). 2012-2018.

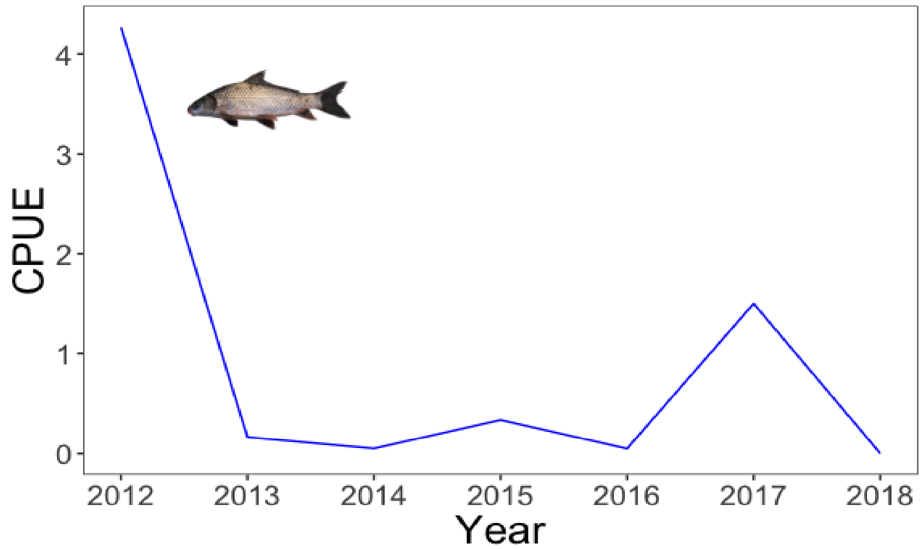


Figure 182. Fykes Annual Average over Fyke 1 and Fyke 2 Stations. *Carassius auratus* (blue). 2012-2018.

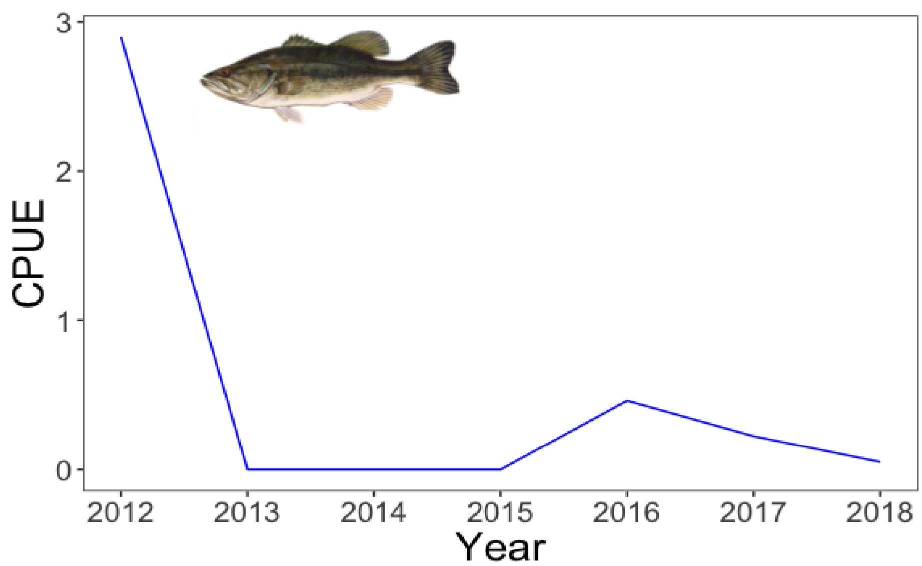


Figure 183. Fykes Annual Average over Fyke 1 and Fyke 2 Stations. *Micropterus salmoides* (blue). 2012-2018.

Long-term Species Composition Changes

The species composition and community structure are changing throughout the time of the survey as indicated by trawl and seine catches. The expansion of SAV beds in the inner cove seems to be driving some of these changes. The main trend related to increasing SAV beds is a decline in White Perch and an increase in Banded Killifish. A detailed multivariate analysis of the community structure shifts in the Gunston Cove fish community since the start of the Gunston Cove survey has recently been published (De Mutsert et al. 2017). Another community shift can be seen in the catfishes. Since the introduction of the invasive Blue Catfish in Gunston Cove in 2001, Blue Catfish has become prevalent in the trawl catches, while the abundances of other catfishes (Brown Bullhead, Channel Catfish, White Catfish) have been declining. The trend in Blue Catfish abundance is currently not increasing, and seems to have reached a plateau. Potentially, a new stable state has been achieved with high Blue Catfish abundances and low abundances of other catfishes. We do collect some Brown Bullhead specimens in the fyke nets, but abundances are low there as well. More fyke net collections are needed to determine if there is a spatial shift of Brown Bullhead towards SAV beds, which would not be unusual for this species that prefers vegetated habitat.

Another interesting community change is an increase in collections of Striped Bass. We only find Striped Bass in low numbers, but because of its high commercial and recreational value, it is worth mentioning. While Striped Bass is thought to occur in more saline waters, this semi-anadromous species does come up to tidal freshwater areas to spawn, and we find juvenile Striped Bass in our seine and trawl collections.

Other observed long-term changes are the decline in Alewife and Blueback Herring. These declines are in concurrence with declines observed coast-wide, and do not have a local cause. It is a combination of declining suitable spawning habitat and overfishing (either targeted fishing that ended in 2012, or as bycatch of the menhaden fishery). Relative high abundances of juvenile Alosines in the trawl and seine samples in 2015 and 2018 could be an indication of the start of a recovery since a moratorium on fishing was imposed in 2012.

With the reported increases and decreases in species abundances it is interesting to evaluate the effect of these community structure changes on the overall diversity of the fish community. This is analyzed by calculating the Simpson's Index of Diversity for each year from 1984 to 2018 (Figure 184, Table 27). The Simpson's Index of Diversity (calculated as $1-(\mathbf{\Sigma}(n_i/N)^2)$) was 0.806 in 2018, and shows no increasing or decreasing trend over time. In this index the communities with higher diversity have higher values (approaching 1). Calculating the index shows that the Cove represents a healthy and stable diversity. Overall, the fish species found in Gunston Cove are characteristic of Potomac River tributaries.

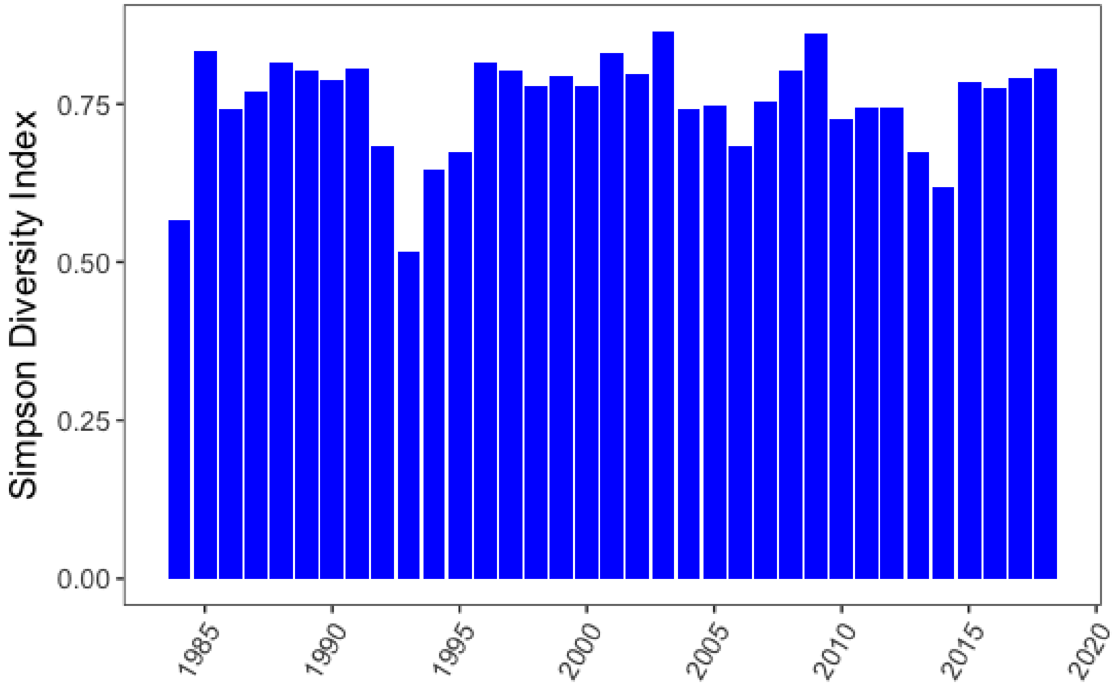


Figure 184. Simpson Diversity Index of fish species collected in Gunston Cove all years.

Table 29. Simpson Diversity Index Values (approaching 1 indicates high diversity).

Year	**Simpson**
2018	0.806
2017	0.792
2016	0.775
2015	0.784
2014	0.619
2013	0.674
2012	0.744
2011	0.744
2010	0.725
2009	0.863
2008	0.802
2007	0.753
2006	0.682
2005	0.746
2004	0.743
2003	0.864

2002	0.798
2001	0.831
2000	0.779
1999	0.794
1998	0.779
1997	0.803
1996	0.816
1995	0.674
1994	0.647
1993	0.518
1992	0.682
1991	0.807
1990	0.788
1989	0.803
1988	0.816
1987	0.771
1986	0.742
1985	0.833
1984	0.565

Summary

In 2018 ichthyoplankton was dominated by clupeids, most of which were Alewife, Gizzard Shad and Blueback Herring, and to a lesser extent, American Shad, and Hickory Shad. White Perch was relatively dominant as well, but with an order of magnitude lower abundance than clupeids. Sunfishes and Inland Silverside was found in relatively high densities as well. White Perch was mostly found in the Potomac mainstem, confirming its affinity for open water. Other taxa were found in very low densities similar to previous years. Clupeid larvae showed a distinct peak early May, which follows the spring spawning run of herring and shad. Most clupeids are spawn from March –May, and are spawn closer to, or even further upstream from, the head of the tide. These larvae then drift down, and remain in tidal tributaries such as Gunston Cove until they are juvenile. They then usually remain several months as juveniles as well, and use Gunston Cove as a nursery.

The trawl, seine and fyke net collections continue to provide valuable information about long-term trends in the fish assemblage of Gunston Cove. The development of extensive beds of SAV over the past decade is providing more favorable conditions for Banded Killifish and several species of sunfish (Bluegill, Pumpkinseed, Redear Sunfish, Redbreast Sunfish, Bluespotted Sunfish, and Green Sunfish) among other species. Indeed, seine and trawl sampling has indicated a relative increase in some of these SAV-associated species. The abundance of some species such as White Perch are showing a decline (while relative abundance of White Perch in this area compared to other species than Banded Killifish remains high). This is likely due to a shift in nekton community structure as a result of the state shift of Gunston Cove to a SAV-dominated system. The shift in fish community structure was clearly linked to the shift in SAV cover with a community structure analysis (De Mutsert et al. 2017). The Simpson's Diversity Index calculated for all years showed that the changes in community structure did not result in significant increasing or decreasing trends in overall diversity in Gunston Cove, and that the diversity is relatively high and stable.

The SAV expansion has called for an addition to the sampling gear used in the survey, since both seines and trawls cannot be deployed where SAV beds are very dense. While drop ring sampling has been successfully used in Gunston Cove in previous years (Krauss and Jones, 2011), this was done in an additional study and is too labor-intensive to add to our semi-monthly sampling routine. In 2012, fyke nets were deployed to sample the SAV beds. The fyke nets proved to be an effective tool to sample the fish community within the vegetation. While fyke-nets do not provide a quantitative assessment of the density of species, it effectively provided a qualitative assessment of the species that reside in the SAV beds. The fyke nets collect mostly several species of sunfish and Banded Killifish, which are indeed species know to be associated with SAV. Reduced efficiency of fyke nets in a year with low SAV cover became clear in 2018, and the most likely reason for that is that fishes can see the nets when they are unobstructed by plants and successfully avoid this stationary gear.

Juvenile anadromous species continue to be an important component of the fish assemblage. We have seen declines in river herring since the mid 1990s, which is in concordance with other surveys around the Potomac and Chesapeake watersheds. In January 2012, a moratorium on river herring was put in effect to alleviate fishing pressure in an effort to help river herring stocks rebound. There were relatively high numbers of juvenile Blueback Herring, Alewife and other Alosines in trawls and seines in 2015. These abundances were lower again in 2016 and 2017, but the successful spawning cohort of 2015 (reported in more detail in the 2015 Anadromous Report) returned to spawn in 2018 as was hypothesized in previous reports (reported in more detail in the 2018 Anadromous Report). The continued monitoring of Gunston Cove since the complete closure of this fishery will help determine if the moratorium results in a recovery of Blueback Herring and Alewife.

G. Benthic Macroinvertebrates Trends: 1994-2018

Benthic invertebrates have been monitored in a consistent fashion since 2009. Those data are assembled below (Table 30), and trends are generally consistent among years. The composition of the benthic macroinvertebrate community at these two sites seems to reflect mainly the texture of bottom substrates. In the cove at Station 7, the bottom sediments are fine and organic with anoxia just below the surface. These conditions favor chironomids and oligochaetes and are not very supportive of the other taxa found in the river. Interestingly, as submerged aquatic vegetation has become more established, gastropods are becoming more abundant and chironomids (midge larvae) are declining. In the river, sediments are coarser and are comprised of a mixture of bivalve shells (mainly *Corbicula*) and sand/silt. This type of substrate supports a wider array of species, as supported by the data from this year showing higher species diversity in the river versus cove.

Oligochaetes are generally the most abundant taxon at both stations (Figure 185). In 2012 and 2013, chironomids were the most abundant taxa, but have consistently been found in lower numbers except for an increase in 2016 at Station 7. Amphipods have generally occurred sporadically at low levels in the cove, but in substantial numbers in the river. In 2014, amphipods were the most abundant organism in the river, but returned to second or third place every year since then. Isopods have been commonly found in the river since 2010 and sporadically in the cove; they reached their highest densities in both sites in 2016. Turbellaria (flatworms) and Hirundinea (leeches) are found in low numbers sporadically at both sites and were present in several river samples since 2014. The consistent finding of even small numbers of taxa other than chironomids and oligochaetes in the cove is encouraging and could be the result of improved water quality conditions in the cove.

Table 30. Benthic macroinvertebrates: annual averages (#/petite ponar)

Taxon	Station 7 (#/petite ponar)						Station 9 (#/petite ponar)					
	2009-13 Avg	2014	2015	2016	2017	2018	2009-13 Avg	2014	2015	2016	2017	2018
Oligochaeta	46.2	26.1	45.1	17.2	13.5	35.2	69.6	9.7	98.2	39.1	40.4	134.8
Amphipoda	1.6	1.7	4.4	3.4	5.5	0.9	23.5	32.6	33.9	11.9	10.2	6.8
Chironomidae	39.5	2.3	3.7	11.6	2.0	4.1	1.3	0.4	5.3	1.1	1.3	2.5
Corbicula	0.1	--	0.9	0.8	0.3	0.1	8.4	--	3.9	0.9	0.5	6.9
Gastropoda	0.4	--	11.9	0.8	0.3	0.4	5.2	--	12.4	1.2	0.2	0.1
Isopoda	0.02	0.1	0.7	1.2	0.4	0	1.9	1.7	6.4	6.8	2.1	3.5
Turbellaria	0.1	0	0.7	0.5	0	0	0.7	2.9	6.3	1.1	0	0.1
Hirundinea	0.4	0.2	0.6	0.1	0	0	0.2	1.2	0.1	0	0	0
Total	**88.7**	**30.4***	**68.2**	**36.4**	**21.9**	**40.7**	**111.1**	**48.5***	**217.1**	**66.3**	**54.7**	**154.7**

For 2009-10, n=8 per station; for 2011-12, n=6 per station; for 2013, 2015-18, n=15 per station; for 2014, n=14 per station.

*Note that molluscs were not enumerated in 2014 due to processing error.

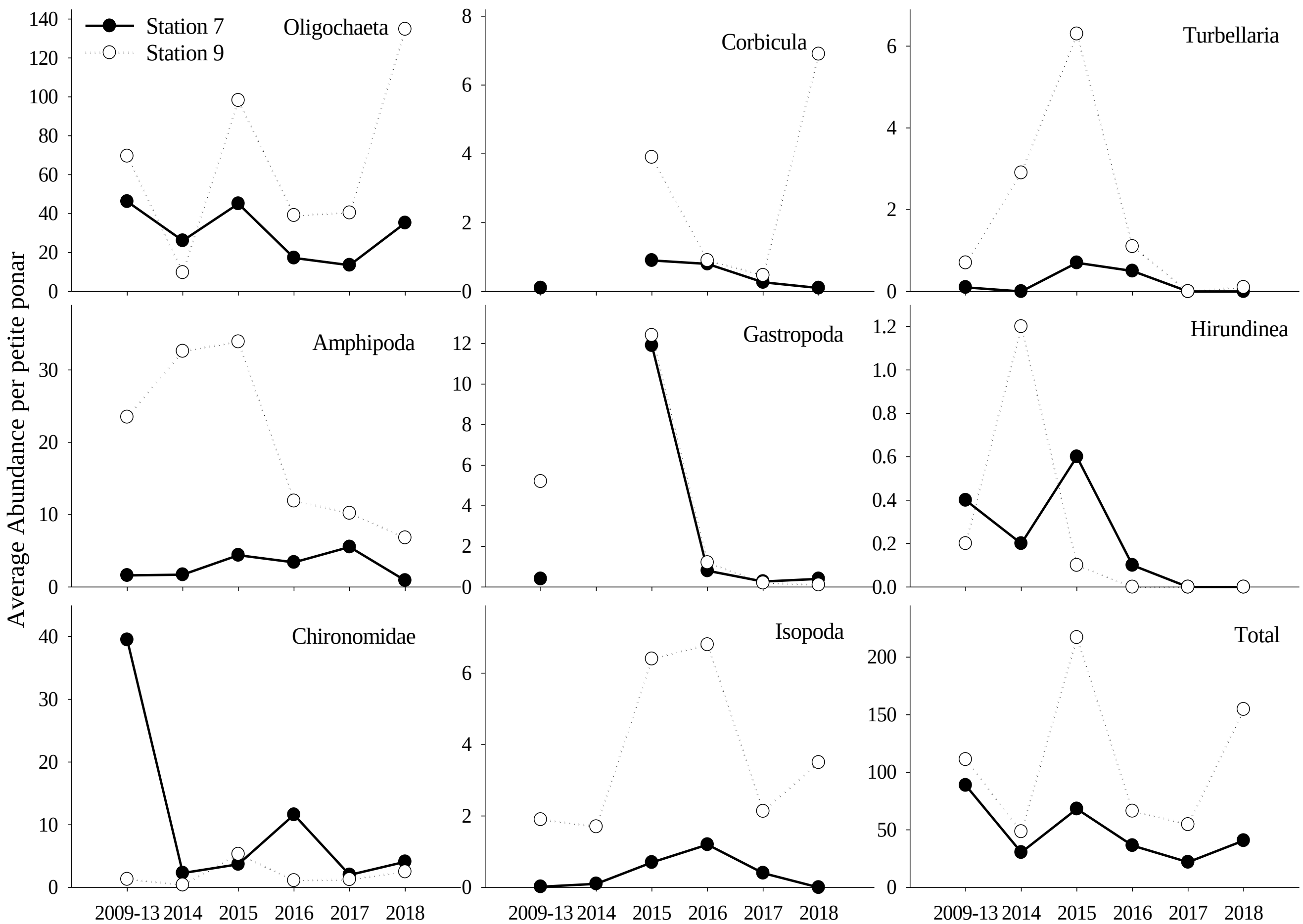


Figure 185. Annual averages of benthic macroinvertebrates separated by station and taxonomic group in Gunston Cove. For 2009-10, n=8 per station; for 2011-12, n=6 per station; for 2013, 2015-2018, n=15 per station; for 2014, n=14 per station. *Note that molluscs were not enumerated in 2014 due to processing error.

H. Submersed Aquatic Vegetation (SAV) Trends: 1994-2018

A comprehensive set of annual surveys of submersed aquatic vegetation in the Gunston Cove area is available on the web at http://www.vims.edu/bio/sav/. This is part of an ongoing effort to document the status and trends of SAV as a measure of Bay recovery by conducting aerial mapping in early fall of each year. Maps of SAV coverage in the Gunston Cove area are available on the web site for the years 1994-2017 except for 2001 and 2011. Unfortunately, aerial mapping was not done in 2018 due to severe weather and poor imagery issues. Although the standardized data was not available, it was obvious that SAV was much reduced in 2018. A plot of SAV vs. Chlorophyll *a* and Secchi disk depth revealed that while chlorophyll remained at near record low levels in 2018, Secchi depth greatly reduced (Figure 186). Thus, the decline in SAV in 2018 was probably due to non-algal turbidity brought in and/or resuspended by the frequent storms in 2018.

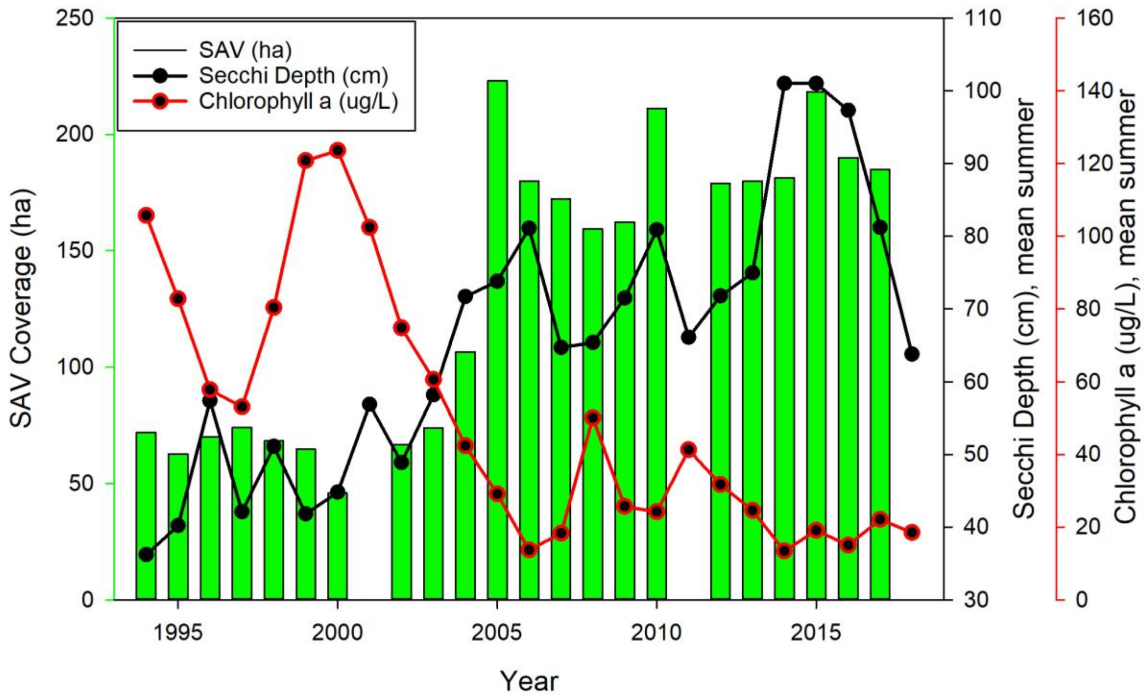


Figure 186. Gunston Cove SAV Coverage. Graphed with average summer (June-September) Depth-integrated Chlorophyll a (µg/L) and Secchi Depth (cm) measured at Station 7 in Gunston Cove.

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Anadromous Fish Survey of Pohick and Accotink Creeks 2018

Final Report
December 2019

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Background

The commercially valuable anadromous fishes in the herring family (Clupeidae) live as adults in the coastal ocean but return to freshwater creeks and rivers to spawn. In the mid-Atlantic region, four species are present: American Shad, Blueback Herring, Alewife, and Hickory Shad.

The American Shad grows to be the largest and spawns in the shallow flats along the Potomac River channel. In the 1700s and early 1800s, incredibly large numbers of American Shad were caught each spring as they came up the river to spawn. The records from 1814-1824 of just one fishery located at Chapman's Landing opposite Mason Neck, Virginia indicate that the annual catch varied from 27,939 to 180,755 American Shad (Massmann 1961). By 1982, the numbers caught in the entire river had dwindled so much that a moratorium was placed on both commercial and sport harvest of the species. In 1995, the Interstate Commission on the Potomac River Basin began a process of capturing ripe American Shad in gill nets off Dogue Creek and Fort Belvoir, stripping eggs from the females, and fertilizing the eggs with milt from males. The resulting young were raised in hatcheries for several days and then released, as fry, in the river below Great Falls (Cummins 2005). Through the 2002 season, over 15.8 million fry were released into the river, and by 2003 - the year after the restoration program ended - the population was judged strong enough to support a limited commercial fishery as bycatch in gill net fisheries. A replacement stocking program had continued (Jim Cummins, pers. comm.), but was terminated in 2017 due to lack of recovery (https://www.dgif.virginia.gov/fishing/shad-restoration/).

Prior to the 1900s, spawning occurred in the river as high as Great Falls (Smith and Bean 1899). In recent years spawning has occurred mostly downriver between Piscataway Creek and Mason Neck (Lippson et al. 1979). We do not normally catch individuals of this species as adults, juveniles, or larvae. The adults are not caught because our trawls mostly sample fishes that stay near the bottom of the water column, and the American Shad remain in the river where the water column is deeper. The juveniles mostly remain in the channel also, but sporadically some juvenile American Shad are captured at our seine stations. Hickory Shad has similar spawning habitats and co-occurs with American Shad, but is less common than American Shad or river herring, and less is known about its life history. Coincident with the appearance of juvenile American Shad at our seine stations, we have also observed small numbers of juvenile Hickory Shad in recent years. Since 2010, we have been catching Hickory Shad adults in Pohick Creek and Accotink Creek.

The Alewife and Blueback Herring, collectively called river herring, are commercially valuable, although typically less valuable than American Shad. In past centuries, their numbers were apparently even greater than those of the American Shad. Massmann (1961) reported that from 1814 to 1824, the annual catch at Chapman's Landing ranged from 343,341 to 1,068,932 fish. The Alewife spawns in tributary creeks of the Potomac River and travels farther into these creeks than do the other species. The Blueback Herring also enters creeks to spawn, but may also utilize downstream tidal embayments to spawn.

River herring were listed in 2006 by NOAA as species of concern due to widespread declining population indices. Population indices of river herring in the Potomac are available from seine surveys of juveniles conducted by MD-DNR. Juvenile catch rate indices are highly variable but have been lower in the last decade for both species (Blueback Herring mean: 1998-2008=0.77 vs. 1959-1997=1.57; Alewife mean: 1998-2008=0.35 vs. 1959-1997=0.55). Since declines continued, a moratorium was established in January 2012, restricting all catches of Alewife and Blueback Herring (4VAC 20-1260-20). Causes of river herring decline are likely a combination of long-term spawning habitat degradation and high mortalities as a result of bycatch in the menhaden fishery. The establishment of a moratorium indicates that declines are widespread, and regular fishing regulations have not been sufficient to rebuild the stock. Using a moratorium to rebuild the stock is also an indication that the cause of the decline is largely unknown. Our monitoring of the river herring spawning population and density of larvae will aid in determining whether the moratorium is halting the decline in river herring abundance.

Another set of economically valuable fishes are the semi-anadromous White Perch and Striped Bass, which are sought after by both the commercial fishery and the sport-fishery. Both spawn in the Potomac River. Striped Bass spawn primarily in the river channel between Mason Neck and Maryland Point, while White Perch spawn primarily further upriver, from Mason Neck to Alexandria, and also in the adjacent tidal embayments (Lippson et al. 1979). Although spawning is concentrated in a relatively small region of the river, offspring produced there spread out to occupy habitats throughout the estuary. These juveniles generally spend the first few years of life in the estuary and may adopt a seasonal migratory pattern when mature. While most Striped Bass adults are migratory (spending non-reproductive periods in coastal seas), recent work indicates that a significant (albeit small) proportion of adults are resident in the estuaries.

Two other herring family species are semi-anadromous and spawn in the area of Gunston Cove. These are Gizzard Shad (*Dorosoma cepedianum*) and Threadfin Shad (*Dorosoma petenense*). Both are very similar morphologically and ecologically, but in our collections, Threadfin Shad are found downriver of Mason Neck, and Gizzard Shad are found upriver of Mason Neck. Neither is commercially valuable, but both are important food sources of larger predatory fishes.

For several years, we have focused a monitoring program on the spawning of these species in Pohick Creek, Accotink Creek, and, less regularly, Dogue Creek. We have sampled for adult individuals each spring since 1988 and for eggs and larvae since 1992. After 16 years of using block nets to capture adults, we shifted in the spring of 2004 to visual observations and seine, dip-net, and cast-net collections. This change in procedures was done to allow more frequent monitoring of spawning activity and to try to determine the length of time the spawning continued. We had to drop Accotink Creek from our sampling in 2005, 2006, and 2007 because of security-related access controls at Fort Belvoir. Fortunately, access to historical sampling locations from Fort Belvoir was regained in 2008. The block net methodology was taken up again in 2008 and has been continued weekly from mid-March to mid-May each year since then. The creeks continuously sampled with this methodology during this period are Pohick Creek and Accotink Creek. Results from our 2018 sampling are presented below. Since the 2015 report, we have included a summary results of the adult abundances from 2008 to present, which shows the changes observed since the period of record that the same sampling methods were used.

Introduction

Since 1988, George Mason University researchers have surveyed spawning river herring in Pohick Creek and adjacent tributaries of the Potomac River. The results have provided information on the annual occurrence and seasonal timing of spawning runs for Alewife (*Alosa* *pseudoharengus*) and Blueback Herring (*A. aestivalis*), but inferences on abundance have been limited for several reasons. The amount of effort to sample spawners has varied greatly between years and the methods have changed such that it is difficult to standardize the numbers captured or observed in order to understand annual fluctuations in abundance. River discharge was also not measured during the previous ichthyoplankton sampling. To maintain coherence with historical efforts while increasing the value of the data from surveys of Pohick and Accotink Creeks, we developed a modified protocol in 2008 with two main objectives: 1) quantify the magnitude of outdrifting larvae and coincident creek discharge rate in order to calculate total larval production; 2) quantify seasonal spawning run timing, size distribution and sex ratio of adult river herring using block nets (a putatively non-selective gear used throughout the majority of the survey). These modifications were accomplished with little additional cost and provided results that are more comparable to assessments in other parts of the range of these species. We have continued this sampling protocol in 2018 in Pohick Creek and Accotink Creek.

Methods

We conducted weekly sampling trips from March 16th to May 25th in 2018. Sampling locations in each creek were located near the limit of tidal influence and as close as possible to historical locations. The sampling location in Accotink creek was moved downstream a bit in 2014, which effectively moved the block net to an area before Accotink creek splits into two branches, which reduces the number of anadromous fishes that could escape through an unsampled branch of the creek. In Pohick Creek the block net remained in the same location. On one day each week, we sampled ichthyoplankton by holding two conical plankton nets with a mouth diameter of 0.25 m and a square mesh size of 0.333 mm in the stream current for 20 minutes. A mechanical flow meter designed for low velocity measurements was suspended in the net opening and provided estimates of water volume filtered by the net. The number of rotations of the flow meter (Counts) attached to the net opening was multiplied by the low speed rotor constant based on the following equation provided by General Oceanics:

Distance (m) = Difference in Counts*Rotor Constant (57560)/999999

The distance could then be used to calculate volume based on the following equation provided by General Oceanics:

Volume (m^3) = ((3.14*(Net Diameter (0.25)^2)/4)*Distance

Larval density (#/m^3) per species was calculated by dividing the number of individuals captured by the volume sampled.

We collected 2 ichthyoplankton samples per week in each creek, and these were spaced out evenly along the stream cross-section. Coincident with plankton samples, we calculated stream discharge rate from measurements of stream cross-section area and current velocity using the following equation:

Depth (m) x Width (m) x Velocity (m/s) = Discharge (m^3/s)

Velocity was measured using a handheld digital flow meter that measures flow in cm/s, which had to be converted to m/s to calculate discharge. Both depth and current velocity were measured at 12 to 20 locations along the cross-section. Sampling dates and procedures completed during each sampling event are listed in Table 1.

Table 1. Procedures completed each sampling date.

Date	Pohick Creek Block net	Pohick Creek Plankton nets	Pohick Creek Cross-section	Pohick Creek YSI	Accotink Creek Block net	Accotink Creek Plankton nets	Accotink Creek Cross-section	Accotink Creek YSI
3/16/18	Y	Y	Y	Y	Y	Y	Y	Y
3/23/18	N*	N*	N*	N*	N*	N*	N*	N*
3/30/18	Y	Y***	Y	Y	Y	Y	Y	Y
4/6/18	Y	Y	Y	Y	Y	Y	Y	Y
4/13/18	Y	Y	Y	Y	Y	Y	Y	Y
4/20/18	Y	Y****	Y	Y	Y	Y	Y	Y
4/28/18	Y	Y	Y	Y	Y	Y	Y	Y
5/4/18	Y	Y****	Y	Y	Y	Y	Y	Y
5/11/18	Y	Y****	Y	Y	Y	Y	Y	Y
5/18/18	N**	N**	N**	N**	N**	N**	N**	N**
5/25/18	Y	Y****	Y	Y	Y	Y	Y	Y

*Field work canceled due to snow
**Field work canceled due to high water flows
***Plankton tows completed for 30 minutes instead of 20.
**** Only 1 plankton tow was sorted and identified due to time constraints

The ichthyoplankton samples were preserved in 70% ethanol and transported to the GMU laboratory for identification and enumeration of fish larvae. Identification of larvae was accomplished with multiple taxonomic resources: primarily Lippson & Moran (1974), Jones et al. (1978), and Walsh et al. (2005). River herring (both species) have demersal eggs (tend to sink to the bottom) that are frequently adhesive. As this situation presents a significant bias, we made no attempts to quantify egg abundance in the samples. We were able to estimate total larval production (P) during the period of sampling by multiplying the larval density (m^{-3}) with total discharge (m^3).

The two river herring species (Blueback Herring and Alewife) are remarkably similar during both larval and adult stages, and distinguishing larvae can be extraordinarily time consuming. Our identification skills have improved over the time of the survey, and we do now distinguish Alewife from Blueback Herring in the larval stage as well as the adult stage. With the improved identification skills, we discovered that Blueback Herring sightings are common enough in our samples that they should be reported in this anadromous report, rather than Gizzard Shad, which is not an anadromous species. From the 2014 report on, the focus of this report is on the two true river herring species, Alewife and Blueback Herring, while presence of other clupeids (herring and shad species) such as Gizzard Shad will still be reported, but not analyzed to the detail of river herring.

The larval stages of two *Dorosoma* species are also extremely difficult to distinguish. However, only Gizzard Shad comes this far upstream, while Threadfin Shad has not been found higher up in the Potomac watershed than Mason Neck. Due to the absence of juveniles in seine and trawl samples from the adjacent Gunston Cove and adjacent Potomac River, we disregarded the possibility that Threadfin Shad were present in our ichthyoplankton samples.

The block net was deployed once each week in the morning and retrieved the following morning (see Figure 1). All fish in the block net were identified, enumerated, and measured. Fish which were ripe enough to easily express eggs or sperm/semen/milt were noted in the field book and in the excel spreadsheet. This also determined their sex. Any river herring that had died or were dying in the net were kept, while all other specimens were released. Fish that were released alive were only measured for standard length to reduce handling time and stress. Dead and dying fish were measured for standard length, fork length and total length. The dead fish were taken to the lab and dissected for ID and sex confirmation.

We used a published regression of fecundity by size and observed sex ratios in our catches to estimate fecundity, and to cross-check whether spawner abundance estimated from adult catches is plausible when compared to number of larvae collected. The following regression to estimate fecundity was used, this regression estimates only eggs ready to be spawned, which gives a more accurate picture than total egg count would (Lake and Schmidt 1997):

Egg # = -90,098 + 588.1(TL mm)

We used data from specimens where both standard length and total length was estimated to convert standard length to total length in cases we had not measured total length. Our data resulted in the following conversion: TL = 1.16SL + 6. The regression had an R^2 of 0.97.

Since the nets were set 24 hours per week for 9 out of the 11 weeks, we approximated total abundance of spawning Alewife and Blueback Herring during the time of collection by extrapolating the mean catch per hour per species during the time the creeks were blocked of over the total collection period as follows:

Total catch/216 hours * 1848 hours = total abundance of spawners

Our total collection period is a good approximation of the total time of the spawning run of Alewife. To determine the number of females we used the proportion of females in the catch for Alewife as well as Blueback Herring, since we are able to sex Blueback Herring as well.

We did not determine the abundance of spawners based on the amount of larvae collected. Alewife and Blueback Herring have fecundities of 60,000-120,000 eggs per female, and with the low numbers of larvae collected, we would grossly underestimate the abundance of spawning fish. Eggs and larvae also suffer very high mortality rates, so it is unlikely that 60,000-120,000 larvae suspended in the total discharge of a creek amount to one spawning female. Instead the method described above was used.

In response to problems with animals tearing holes in our nets in earlier years, we have been consistently using a fence device that significantly reduces this problem. The device effectively excluded otters and similar destructive wildlife, but had slots that allowed up-running fish to be captured. The catch was primarily Clupeids with little or no bycatch of other species.

Figure 1. Block net deployed in Pohick creek. The top of the block net is exposed at both high and low tide to avoid drowning turtles, otters, or other air-breathing vertebrates. The hedging is angled downstream in order to funnel up-migrating herring into the opening of the net.

Results

Our creek sampling work in 2018 spanned a total of 11 weeks, during which we collected 36 ichthyoplankton samples, and 18 adult (block net) samples. In 2010, Hickory Shad (*Alosa mediocris*) was captured for the first time in the history of the survey, after which we have continued to observe Hickory Shad in our samples. Hickory Shad are known to spawn in the mainstem of the Potomac River, and although their ecology is poorly understood, populations of this species in several other systems have become extirpated or their status is the object of concern. This year we captured 2 adult Hickory Shad specimens in Accotink Creek and 15 adult Hickory Shad specimens in Pohick Creek.

The abundance of confirmed *Alosa* larvae was much higher than last year (922 versus 144 last year). The numbers of unidentified clupeid larvae were even higher than the unprecedented levels (for the period of record) of 2015, with 4637 unidentified clupeids, which could be *Alosa* or *Dorosoma*; Gizzard Shad). The unidentified larvae were too damaged to be identified to the species level, which likely occurred through a combination of high flow and high larval densities in the net. We also collected 1881 identified Gizzard Shad larvae. We found that the *Alosa* larvae consisted of Blueback Herring and Alewife larvae (Table 2). Like last year, we did find adults of Hickory Shad, but no larvae.

Table 2. Larval and adult catch of clupeids collected in both creeks in 2018. 'All Adults' includes the specimens that could not be sexed.

	Accotink				Pohick			
Species	# Larvae	# Female	# Male	# All Adults	# Larvae	# Female	# Male	# All Adults
Blueback Herring	84	0	1	35	165	11	28	109
Hickory Shad	0	0	0	2	0	5	4	15
Alewife	219	1	26	233	454	28	111	1243
Gizzard Shad	722	2	4	13	1159	0	5	16
Unk. Clupeids	2911	0	0	0	1726	0	0	1

We measured creek discharge at the same locations and times where ichthyoplankton samples were taken. Both creeks showed a similar discharge pattern (Figure 2), with consistently higher discharge in Pohick Creek than in Accotink Creek, which is similar as in previous years. During the 77-day sampling period (which roughly coincides with the river herring spawning period), the total discharge was estimated to be on the order of 3.7 and 8.8 million cubic meters for Accotink and Pohick creeks, respectively (Table 3), which is lower than last year.

Larval density of Alewife exhibited a peak in Accotink Creek in mid-April (Figure 3a). Larval densities in Pohick Creek displayed a very high peak in early April this year, accounting for most of the larvae found in 2018 (Figure 3a). Given the observed mean densities of larvae and the total discharge, the total production of Alewife larvae was estimated at over 2.2 million and 6.2 million for Accotink Creek and Pohick Creek, respectively (Table 3). Blueback Herring larval density was lower leading to total larval production estimates of close to 400 thousand and 2 million for Accotink Creek and Pohick Creek, respectively.

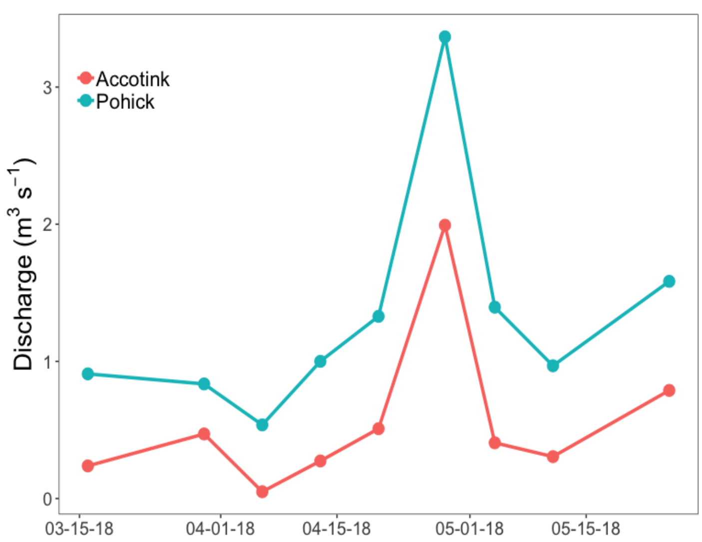

Figure 2. Discharge rate in $m^3 s^{-1}$ measured in Pohick and Accotink creeks during 2018.

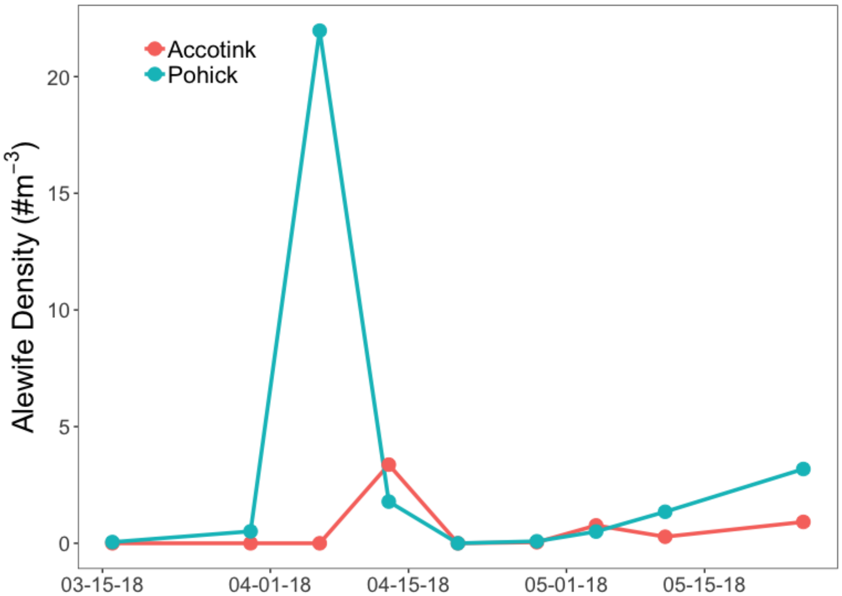

Figure 3a. Density of larval *Alosa pseudoharengus* in # m^{-3} observed in Pohick Creek and Accotink Creek in 2018.

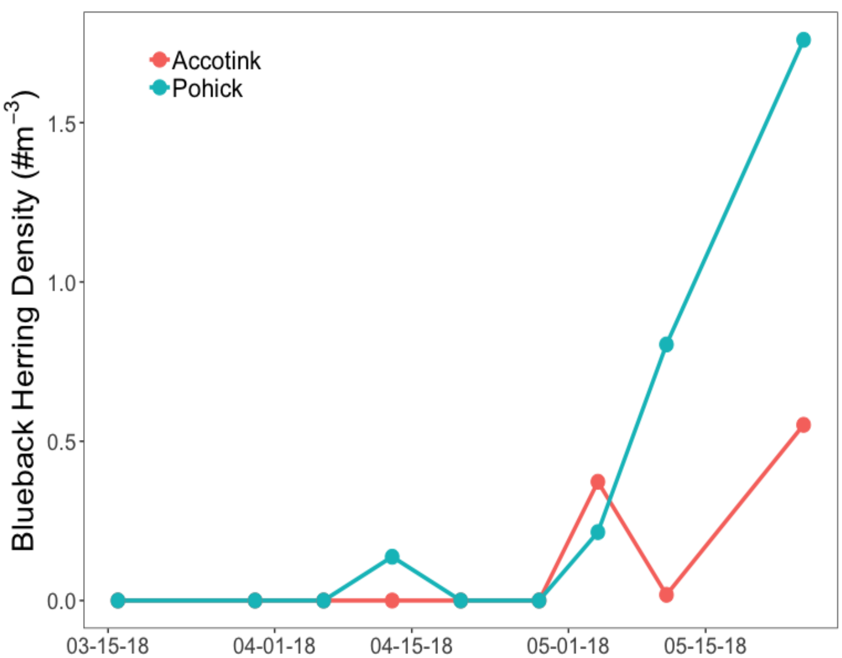

Figure 3b. Density of larval *Alosa aestivalis* in # m^{-3} observed in Pohick Creek and Accotink Creek in 2018.

In the block nets, a very high number of Alewife adults were captured, which signals the return of the successful 2015 year-class; 1476 adults were collected (Table 2). Blueback Herring were collected in high numbers, but not to the extent of Alewife or to the extent of the number of Blueback herring in 2015; 144 adults were collected. Of those captured, 166 Alewife and 40 Blueback Herring were sexed, providing us with sex ratios (Table 3, although in Accotink Creek only 1 Blueback Herring was sexed, which did not allow for estimating a sex ratio). Skewed sex ratios in fish populations are common. The total abundance of spawning Alewife was estimated to be 7910 in Pohick Creek during the period of sampling, and 1486 in Accotink Creek. The size of the spawning population of Blueback Herring was estimated to be 693 in Pohick Creek, and 226 in Accotink Creek this year.

Table 3. Estimation of *Alosa pseudoharengus* and *A. aestivalis* fecundity and spawner abundance from Accotink and Pohick creeks during spring 2018.

Parameter	Accotink	Pohick
Creek flow		
Mean discharge (m^3s^{-1})	0.559	1.325
Minimum discharge (m^3s^{-1})	0.050	0.537
Maximum discharge (m^3s^{-1})	1.993	3.366
Total discharge, (m^3)	3,718,915.2	8,813,629.44
Alewife		
Mean Alewife larvae density (# m^{-3})	0.597	0.707
Total Alewife Larval Production	2,221,529.12	6,235,575.21
Adult Alewife Mean Standard Length (mm)	229.3	232.3
Alewife Fecundity	75,650.1	77,719
Alewife Sex Ratio	0.00524	0.023
Estimated number of female Alewife	8	179
Estimated total number of Alewife	1,486	7,910
Blueback Herring		
Mean Blueback Herring larvae density (# m^{-3})	0.105	0.218
Total Blueback Herring Larval Production	389,341.74	1,922,415.44
Adult Blueback Herring Mean Standard Length (mm)	210.4	224.8
Blueback Herring Fecundity	62,866	72,188
Blueback Herring Sex Ratio	NA	0.101
Estimated number of female Blueback Herring	NA	70
Estimated total number of Blueback Herring	226	693

Discussion

Summary 2018

We caught 1476 adult Alewife and 144 adult Blueback Herring; we have positively identified Blueback Herring in this survey since 2011. We also collected 17 Hickory Shad. These numbers are on the same order of magnitude as what we collected in 2015, which shows the anticipated return of the successful 2015 year-class has indeed happened, at least for Alewife (Figure 4). The estimated size of the spawning population of Alewife is close to ten thousand fishes in the Gunston Cove watershed in 2018. We estimated about a tenth of that for Blueback Herring, numbers were higher in Pohick Creek than Accotink Creek; this is likely a temperature effect. Blueback Herring prefer to spawn at higher temperatures than Alewife; >13 °C versus >10.5 °C for Alewife (Fay et al. 1983). By receiving effluent for the Noman Cole pollution control plant, Pohick Creek is slightly warmer than Accotink Creek. The fact that blueback herring prefer higher temperatures to spawn is likely contributing to the finding of lower abundances during our sampling period as well; Blueback herring spawn later into the season, and we are really only capturing the start of the blueback herring spawning season. Our sampling season is based on Alewife's spawning season, since originally George Mason researchers did not expect to find Blueback Herring in these creeks. A spawning population of Blueback Herring has been confirmed in this area since 2011, and we will continue to provide population parameters of Blueback Herring in our reports. A potential trend of earlier warmer temperatures in spring has moved Blueback Herring spawning season to overlap more with Alewife spawning season over time, which could explain why they did not find Blueback Herring during this time period in the past. This hypothesis warrants further investigation.

Trends through time

With a moratorium established in 2012 in Virginia, in conjunction with moratoria in other states connected to the north Atlantic at the same time or earlier, the order of magnitude increase in Alewife and Blueback Herring abundance three years after this occurrence (in 2015) could be a result of the moratoria. The moratoria prohibit the capture and/or possession of river herring (Alewife and Blueback Herring). The three-year delay coincides with the time it takes for river herring to mature, which means this is the first year a cohort has been protected under the moratoria for a complete life cycle. The lower numbers in 2016 and 2017 (while the moratoria are still in effect), indicate that the high abundances in 2015 are not just an effect of the moratoria, but perhaps a combination of that and having a good year class in 2015. Since it takes about 3 years for river herring to return as spawning adults from the time they were spawn as ichthyoplankton, we were hopeful for a strong return in 2018. This has indeed materialized for Alewife, which is very encouraging. While Blueback Herring numbers were lower, it could be the case that we are not fully capturing Blueback Herring's spawning period during our sampling period, as explained above.

Through meetings with the Technical Expert Working group for river herring (TEWG; http://www.greateratlantic.fisheries.noaa.gov/protected/riverherring/tewg/index.html) it has become clear that not all tributaries of the Chesapeake Bay, in Virginia and elsewhere, have seen increased abundances as we are seeing here; some surveyors even reported declines (De Mutsert, personal communication). Since the general historic decline in river herring was related both to overfishing and habitat degradation, it could be the case that habitat in those areas has not recovered sufficiently to support a larger spawning population now that fishing pressure is released. This while the habitat in the Gunston Cove watershed is of suitable quality to support a larger spawning population now that reduced fishing pressure allows for more adults to return to their natal streams. Additional stressors could play a role in the variable success so far of the moratoria; while targeted catch of river herring is prohibited, river herring is still a portion of by-catch, notably of offshore midwater trawl fisheries (Bethoney et al. 2014).

For the Gunston Cove watershed, 2018 was a highly productive year for Alewife, and above average for Blueback Herring (Figure 4). Table 4 shows a summary of adult clupeid abundance collected in block nets from 2008-2018. Catch per unit effort (CPUE) is used in these time series, which reflect the average catch per block net, to be able to compare years while the nets are not set the same amount of times in each year.

Table 4. The CPUE of four Clupeid species that occur in this area captured with block net during the spawning season.

	Accotink				Pohick			
Year	Blueback Herring	Hickory Shad	Alewife	Gizzard Shad	Blueback Herring	Hickory Shad	Alewife	Gizzard Shad
2008	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.3
2009	0.0	0.0	0.6	0.1	0.0	0.0	3.3	0.2
2010	0.0	0.0	7.7	0.0	0.0	3.1	11.0	0.0
2011	0.1	1.2	4.7	4.2	0.6	0.6	6.0	2.2
2012	0.0	0.0	1.2	0.2	0.7	0.3	5.8	0.5
2013	0.0	0.1	2.9	0.2	0.4	0.0	5.3	1.7
2014	0.0	0.1	0.7	2.5	1.6	0.5	5.5	1.9
2015	0.2	0.0	37.9	6.8	61.3	20.9	59.5	13.0
2016	0.9	0.0	7.6	10.8	8.0	2.1	9.4	0.8
2017	0.0	0.0	2.4	0.3	3.4	0.7	10.4	0.9
2018	3.2	0.2	21.2	1.2	9.9	1.3	113.0	1.4

While it is too soon to tell what the long-term effects of the moratorium will be, and to what extent it affects the abundances in Potomac River tributaries, continued monitoring will determine whether some pattern of higher abundances is maintained in subsequent years. To truly capture Blueback Herring abundances we may need to extend the sampling season, since especially the larval densities seem to be highest late in our sampling period.

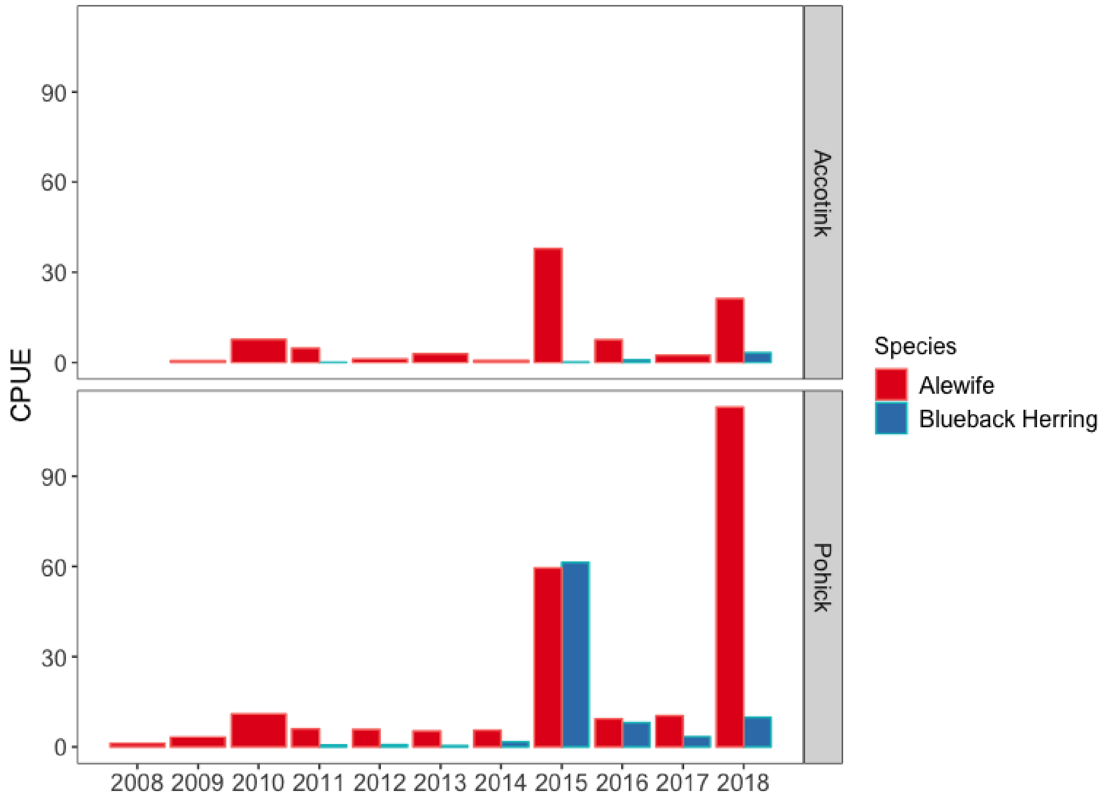

Figure 4. The CPUE of *Alosa pseudoharengus* (number of individuals) and *A. aestivalis* collected with the block net in each year.

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