An Ecological Study of Gunston Cove

2019

FINAL REPORT

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by

R. Christian Jones
Professor
Department of Environmental Science and Policy
Director
Potomac Environmental Research and Education Center
George Mason University
Project Director

Kim de Mutsert
Assistant Professor
Department of Environmental Science and Policy
Associate Director
Potomac Environmental Research and Education Center
George Mason University

Amy Fowler
Assistant Professor
Department of Environmental Science and Policy
Faculty Fellow
Potomac Environmental Research and Education Center
George Mason University

to

Department of Public Works and Environmental Services
County of Fairfax, VA

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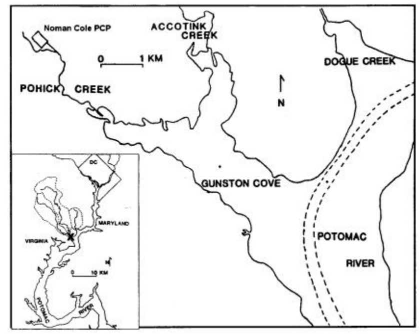
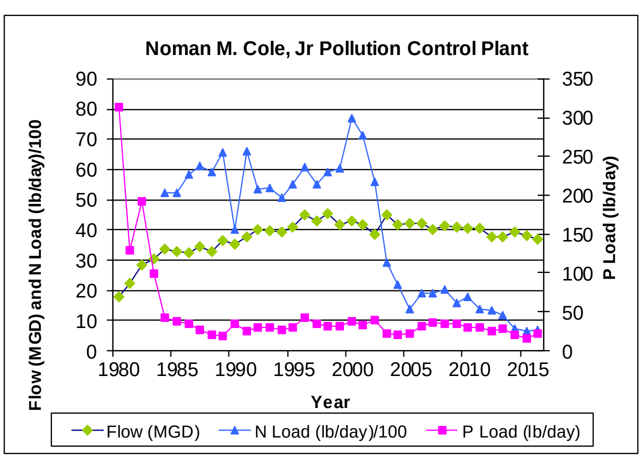
Executive Summary



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 2019 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.



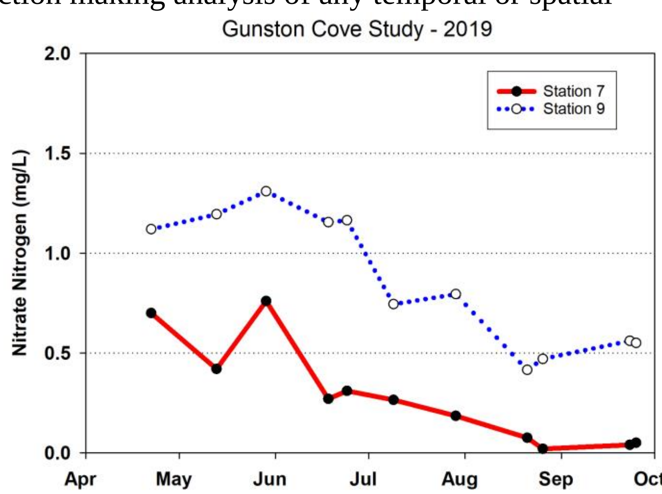
As shown in the figure to the left, phosphorus loadings were dramatically reduced in the early 1980's. In the last several years, nitrogen, and solids loadings as well as effluent chlorine concentrations have also been greatly reduced or eliminated. These reductions have been achieved even as flow through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

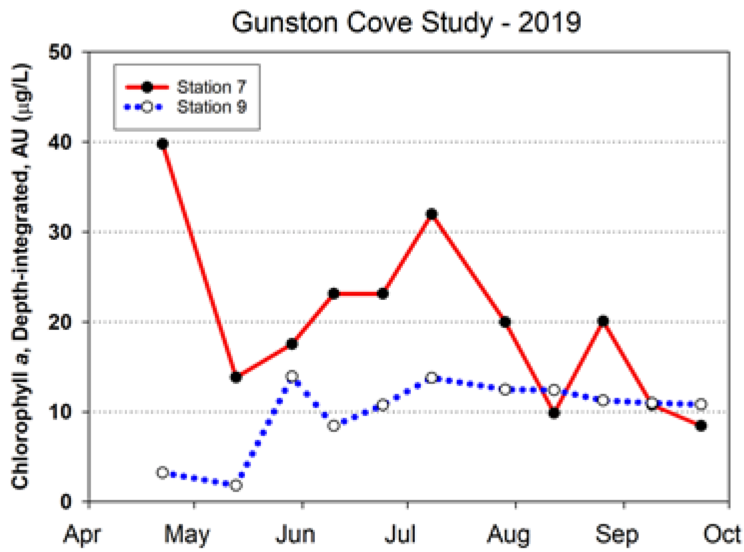
In 2019 air temperature was above average from April through September. Precipitation was above normal from May through July, but below normal in August and September. Rainfall and runoff patterns relative to sampling dates are shown in Figure 77. The water quality sample dates that were preceeded by substantial rainfall were May 13 and, especially, July 8. On July 6, 1.7 cm of rain fell and then on July 8 there was 8.7 cm of rain. River flows which could impact the study area followed the typical seasonal pattern. In March and April flows were near normal, but in May and again in July, they were substantially elevated. In general, rainfall and subsequent runoff was near nformal in 2019 compared with the very high runoff in 2018.

Mean water temperature was similar at the two stations with a pronounced dip in early June and a peak of about 30° in July. Specific conductance exhibited a gradual rise throughout the study period at both stations and showed little response flow events. Dissolved oxygen saturation and concentration (DO) were more variable in the cove and there was little seasonal pattern at either site. Field pH patterns mirrored those in DO. Total alkalinity was generally higher in the river than in the cove. In the cove the two major dips in total alkalinity corresponded to the two dates preceded by substantial rainfall. Water clarity as measured by Secchi disk transparency and light attenuation coefficient quite similar at the two station for most of the year although more variability was exhibited in the Cove. In the cove water clarity dropped on one of the high rainfall dates, July 8, and increased dramatically in September.

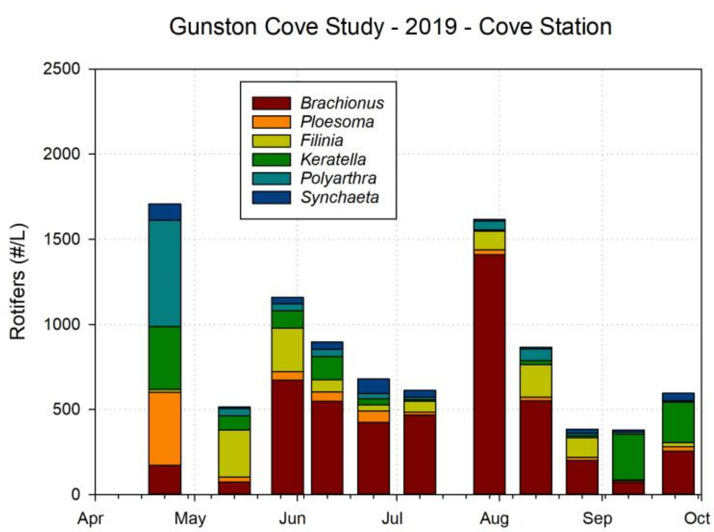
Ammonia nitrogen was consistently low in the study area during 2019, but almost all values were below the limits of detection making analysis of any temporal or spatial trends impossible. Nitrate values (right) declined steadily through the entire study period at both stations with river values consistently about 0.5 mg/L than those in the cove. Nitrite was much lower overall. Organic nitrogen showed a general seasonal decline punctuated by a major dip in late May. Total phosphorus showed a major peak corresponding to the early July runoff event. Soluble reactive phosphorus was generally



somewhat higher in the river, but showed little seasonal trend. N to P ratio did not show a consistent seasonal pattern, but was generally in the 12-40 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 July runoff event. VSS did not show strong spatial and temporal patterns.



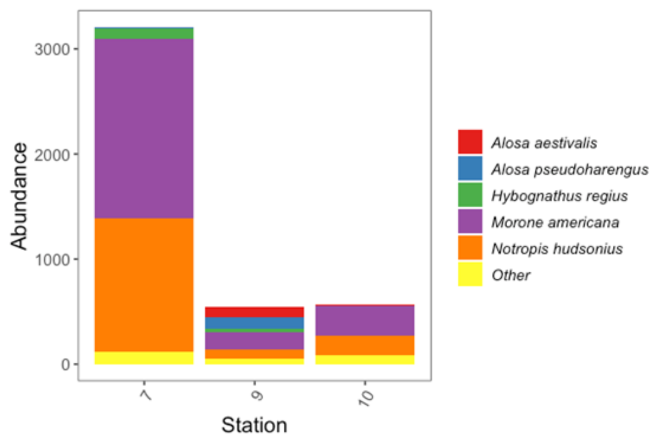
In the cove algal populations as measured by chlorophyll *a* were consistently higher in the cove than in the river through most of the year (right). High values in the cove in April were strongly decreased in early May, a possible flow impact. A steady increase followed through early July and then a decline through the remainder of the year. The April maximum was composed predominantly of diatoms with *Melosira* being the most important. In the river phytoplankton chlorophyll was generally lower than in the cove and pennate diatoms were dominant in April while euglenoids were most important in May and June.



Rotifers continued to be the most numerous microzooplankton in 2019. Rotifer densities were unusually high in April in the cove with mixed taxa dominance. A decline in early May in the wake of the flow event was following by generally higher but declining values until a peak in lat July. In June *Brachionus* became the dominant rotifer for the remainder of the year at both stations (left). Rotifer densities were consistently lower in the river than in the cove with peaks in late May and early August. *Bosmina*, a small cladoceran was low at both stations in 2019. *Diaphanosoma*, a larger cladoceran, was much more common in the river with marked peaks in early June and early July. *Daphnia* was only found at low values in 2019. *Sida* was present in the river at the same times as *Diaphanosoma*. *Leptodora* exhibited a peak in early May in the cove and early June in the river. Copepod nauplii were found in variable numbers in the cove and had a distince seasonal pattern in the river with highest values from June through early July. The calanoid copepod *Eurytemora* was very abundant in the cove in April but was much lower for the rest of ther year. It showed strong peaks in early June and early July in the river. A second calanoid *Diaptomus* was found at much lower levels, mainly in April in the cove. Cyclopoid copepods had a strong maximum in the river in July, but otherwise were at low levels.

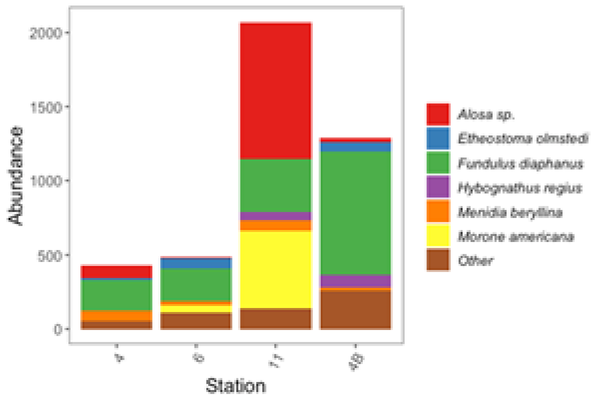
In 2019 ichthyoplankton was dominated by clupeids, most of which were Alewife, Gizzard Shad, and Blueback Herring, and to a lesser extent Hickory Shad, and American Shad. Although clupeids constituted more than 90% of the catch, 13 different species were identified in the ichthyoplankton samples. Of 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 late May, which was driven by a high density of Clupeid larvae. The non-clupeid larval density was highest in mid-May, which was driven by White Perch larvae.

Submerged aquatic vegetation returned in 2019 after 2018's very low cover, which resulted in fish abundances and gear efficiency that was similar to the years before 2018. In trawls (right), White Perch dominated, followed by Spottail Shiner. White Perch was by far the most abundant species and was found in all months at all stations, with peak abundance in June. We collected a lot less Blue Catfish than last year, but still 13 in the mainstem and 1 in the cove. Abundances have likely not reduced since last year, large specimens tend to avoid our gear.



Last year more than a hundred invasive Blue Catfishes were collected with the trawl, of which only one in the cove and the rest in the mainstem. With the smaller catch in 2019, we still found a 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 four native catfishes in the cove and none in the mainstem.

In seines, the most abundant species was Banded Killifish. 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 August. Other taxa with high abundances were Herring and Shad, with a similar abundance pattern as Banded Killifish. Numerous small Alosa juveniles started appearing in the samples in late May, 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

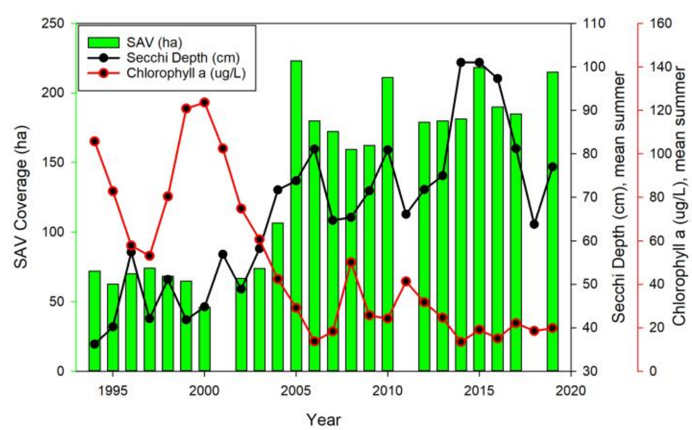


seines were White Perch, Inland Silverside, Tessellated Darter and Eastern Silvery Minnow (left).

Fyke nets were part of the sampling regime again in 2019. The total catch of the fyke nets is smaller than the other gears, and was similar again to previous years after low SAV cover rendered the 2018 Fyke net catch very small. Fyke nets represent 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 in addition to Banded Killifish, which are underrepresented in the seine and trawl catches since they tend to stay within the SAV. Sunfishes that could be identified to the species level were represented in order of abundance by Bluegill, Pumpkinseed, and Redear Sunfish. Highest abundance of all species collected with fyke nets occurred in August, when SAV cover is most extensive.

As in most previous years, oligochaetes were the most common invertebrates collected in ponar samples in 2019. Chironomids (midge larvae) were second most dominant in the cove. Amphipods, isopods, and chironomids were common in the river. Multivariate analysis showed a clear and consistent difference between cove benthic communities and those in the river. Shells were the most dominant large substrate in river benthic samples. In the cove both shells and plant detritus were abundant.

Coverage of submersed aquatic vegetation (SAV) in 2019 rebounded very strongly after very limited abundances in 2018 due to high turbidity and subsequent low light levels. *Hydrilla*, minor naiad, and water stargrass were the most abundant SAV. Standaridized data on SAV coverage from VIMS resumed in 2019 and continues to show a major sustained improvement in water clarity and subsequent recovery of SAV beds. Jones (2020) demonstrated that the cove ecosystem changed from a “turbid water” state dominated by phytoplankton to a “clear water” state dominated by SAV in 2005. As shown in the figure above the data for 2019 indicates that the “clear water” state is continuing with improved water clarity (Secchi depth), lower phytoplankton (chlorophyll a), and greater coverage of SAV as indicated in the graph above.

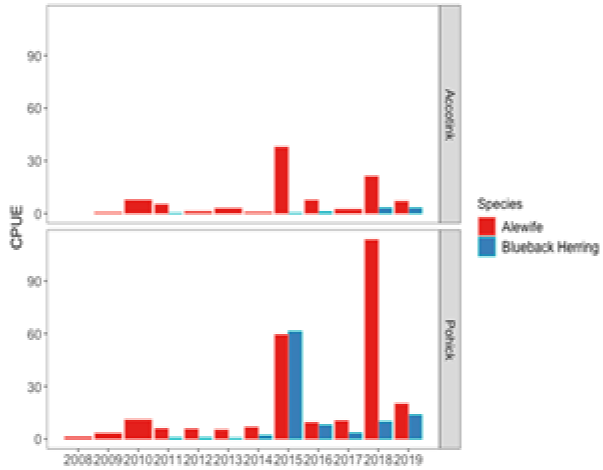


A second significant change in water quality documented by the study has been the removal of chlorine and ammonia from the Noman M. Cole, Jr. Pollution Control Plant effluent. A decline of over an order of magnitude in ammonia nitrogen has been observed in the Cove as compared to earlier years. The declines 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 the change 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, 2019 was an above average, but not record, year for Alewife and Blueback Herring (see figure below). The estimated size of the spawning population of Alewife was about 1750 in 2019 compared with about 9400 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 large increase in Alewife and Blueback Herring abundance 3-4 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 delay coincides with the time it takes for river herring to mature, which means these are the first years 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.



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 was highly instructive in showing how extreme rainfall conditions can alter the ecosystem and at least temporarily impede recovery. However, 2019 data indicate that the ecosystem was resilient and resumed the “clear water” state in 2019.

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. We continue to recommend that this be addressed.

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. 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.

Reference: Jones, R.C. 2020. Recovery of a Tidal Freshwater Embayment from Eutrophication: a Multidecadal Study. *Estuaries and Coasts*. Forthcoming in print. Available online at: https://link.springer.com/article/10.1007/s12237-020-00730-3

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

THE ONGOING AQUATIC MONITORING PROGRAM

FOR THE GUNSTON COVE AREA

OF THE TIDAL FRESHWATER POTOMAC RIVER

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R. Christian Jones
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Kim de Mutsert
Assistant Professor
Department of Environmental Science and Policy
Associate Director
Potomac Environmental Research and Education Center
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Co-Principal Investigator

Amy Fowler
Assistant Professor
Department of Environmental Science and Policy
Faculty Fellow
Potomac Environmental Research and Education Center
George Mason University
Co-Principal Investigator

to

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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 Steve Winesett, 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, Rachel Kelmartin, Julia Czarnecki, Chris Bodner, Tanya Ramseyer, Chris Martin, Sara Marriott, Alex Mott, Katherine Russell, Sam Mohney, Haley Haasch, Bryce Bossuot, James Burmeister, Daria Malyukova, Keith Keel, and Eran Nimtz. Claire Buchanan served as a voluntary consultant on plankton identification. Cheryl Skolnick, Francina Osaria, Florencia Gutierrez, and Hillary Hamm were vital in handling budget, 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.

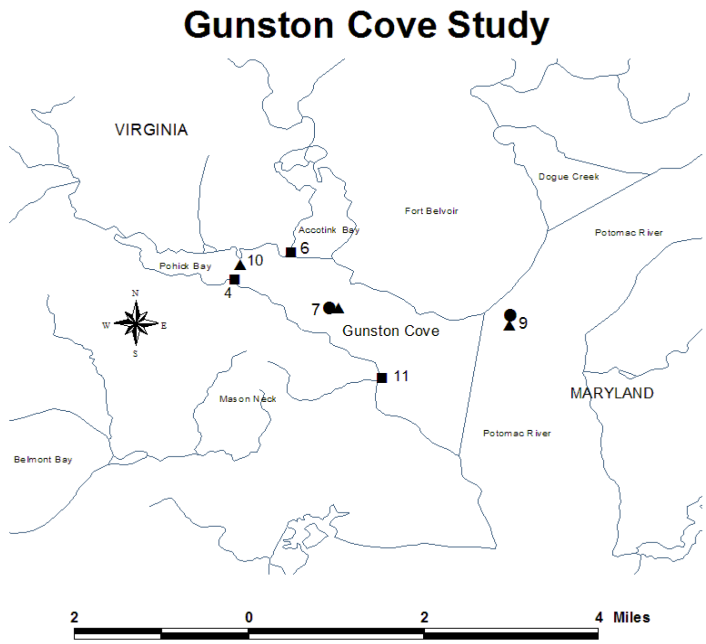


Figure 1a. Gunston Cove area of the Tidal Potomac River showing sampling stations. Circles (●) represent Plankton/Profile stations, triangles (▲) represent Fish Trawl stations, and squares (■) represent Fish Seine stations.

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

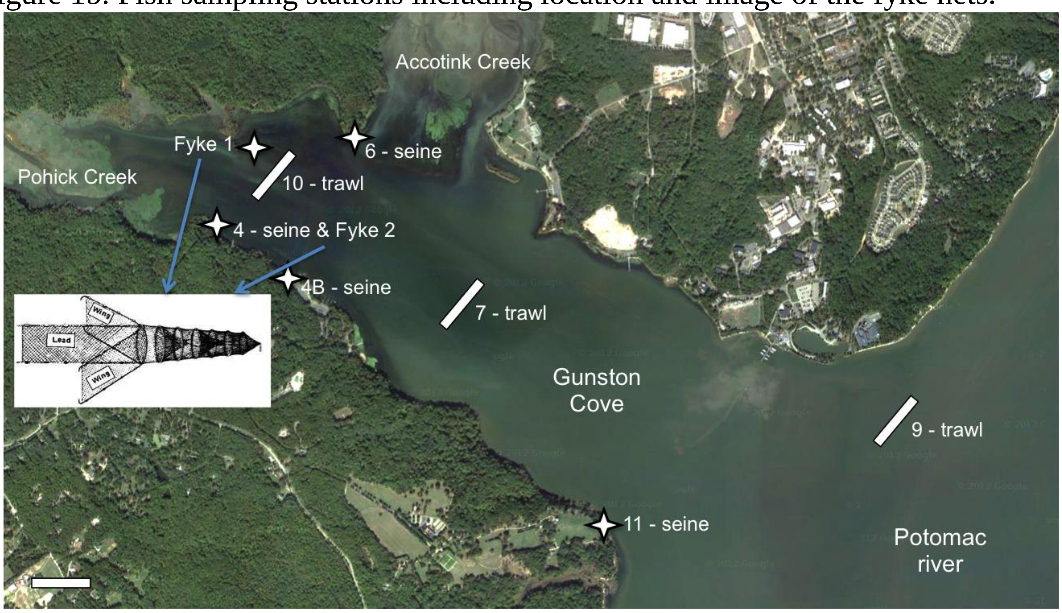


Table 1
Sampling Dates and Weather Data for 2019

	Type of Sampling					Avg Daily Temp (ºC)		Precipitation (cm)	
Date	G	F	T	S	Y	1-Day	3-Day	1-Day	3-Day
Apr 22	G	F				18.3	18.3	0	T
Apr 26			T	S		20.0	20.9	1.50	1.50
May 9			T	S	Y	21.1	21.1	T	T
May 13	G	F*				12.8	15.0	1.50	3.78
May 16		F*				20.0	17.2	0.03	0.03
May 20			T	S	Y	27.8	25.2	T	0.61
May 29	G	F				28.9	27.2	0	0.48
Jun 4			T	S	Y	18.9	20.9	0	T
Jun 10	G					21.7	22.4	0.94	1.27
Jun 18			T	S	Y	26.7	26.9	2.95	5.47
Jun 24	G	F				26.1	24.4	0.05	0.05
Jul 2			T	S	Y	22.8	25.7	1.07	1.07
Jul 8	G					24.4	26.9	8.47	10.57
Jul 9		F*				25.0	25.7	0	8.47
Jul 16			T	S	Y	31.1	30.2	0	0.74
Jul 29	G	F				29.4	28.1	0	0
Aug 6			T	S	Y	27.8	28.0	0	T
Aug 12	G					27.2	25.6	0	0
Aug 21		F*	T	S	Y	28.3	29.6	0.03	0.95
Aug 26	G	F				21.1	22.2	0	T
Sep 9	G					25.6	24.3	T	T
Sep 13			T	S	Y	22.2	26.7	T	0.11
Sep 23	G	F				28.3	26.7	0	0
Sep 25		F*				22.8	24.8	0	0

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.

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 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 - 2019

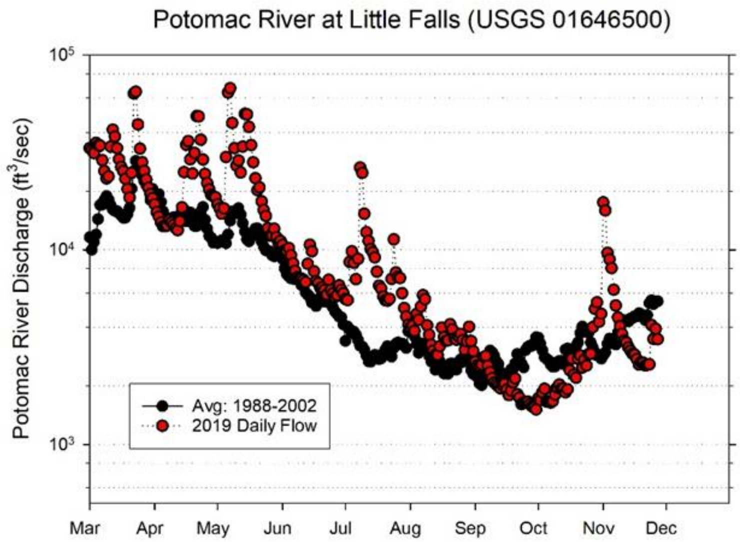
In 2019 temperature was above normal for the entire study period from April through September (Table 2). April, May, and September were more than 3°C above normal. There were 48 days with maximum temperature above 32.2ºC (90ºF) in 2019 which is above the median number over the past decade. Precipitation was well above normal from May through June, but was very much below normal in August and September. The largest daily rainfall total was 8.7 cm on July 8. Another period of heavy precipitation was June 18/19 when with a total of 5.5 cm between the two days. Even so, precipitation in 2019 was below the record year of 2018. River and stream flows in 2019 were generally near average except in July when flows were substantially above average and in September when they were substantially below average (Table 3). As with precipitation, flows in 2019 were well below the record flows of 2018.

Table 2. Meteorological Data for 2019. National Airport. Monthly Summary.

MONTH	Air Temp (ºC)		Precipitation (cm)	
March	8.2	(8.1)	10.2	(9.1)
April	16.9	(13.4)	5.7	(7.0)
May	21.7	(18.7)	12.6	(9.7)
June	24.7	(23.6)	10.8	(8.0)
July	27.8	(26.2)	16.5	(9.3)
August	26.7	(25.2)	5.0	(8.7)
September	24.7	(21.4)	0.6	(9.6)
October	17.8	(14.9)	16.9	(8.2)

Table 3. Monthly mean discharge at USGS Stations representing freshwater flow into the study area. (+) 2019 month > 2x Long Term Avg. (-) 2019 month < ½ Long Term Avg.

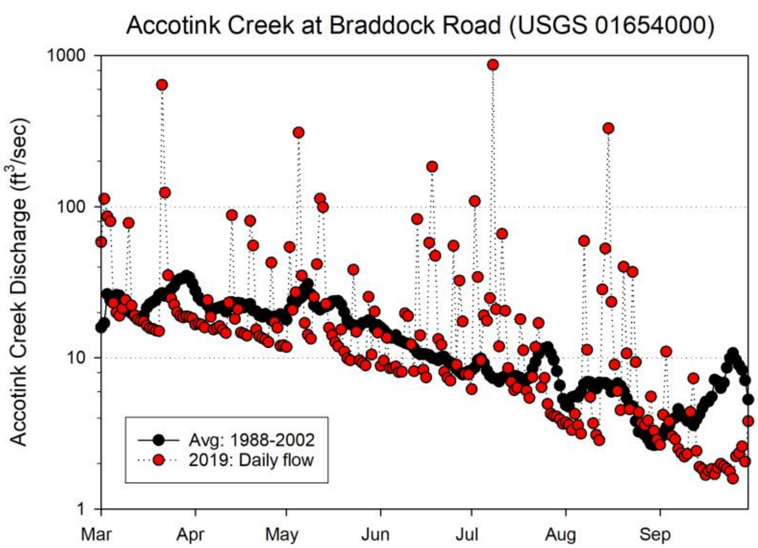
	Potomac River at Little Falls (cfs)		**Accotink Creek at Braddock Rd (cfs)**	
	2019	**Long Term Avg.**	**2019**	**Long Term Avg.**
March	30848	23600	53.4	42
April	22170	20400	22.8	36
May	26419	15000	34.1	34
June	7539	9030	23.8	28
July	8902 (+)	4820	43.7 (+)	22
August	3784	4550	22.3	22
September	2044 (-)	5040	2.9 (-)	27



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: 2019. 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 and stream flow when compared to long-term averages (Figures 2 and 3). River flow in 2019 tracked long term averages fairly closely except in April and May and July when it was substantially above normal and in September and October when it was substantially below normal (Figure 2). Local inflow to the cove from Accotink followed the long-term pattern of decreasing base flow through the summer punctuated by storm flows (Figure 3). The high flows were most frequent in late June/early July and during August.



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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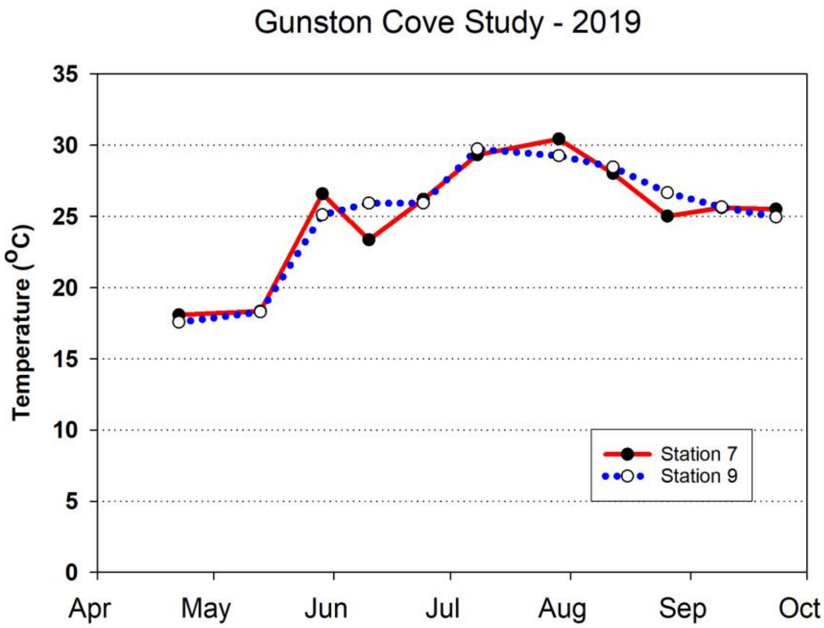
Figure 3. Mean Daily Discharge: 2019. Accotink Creek at Braddock Road (USGS Data).

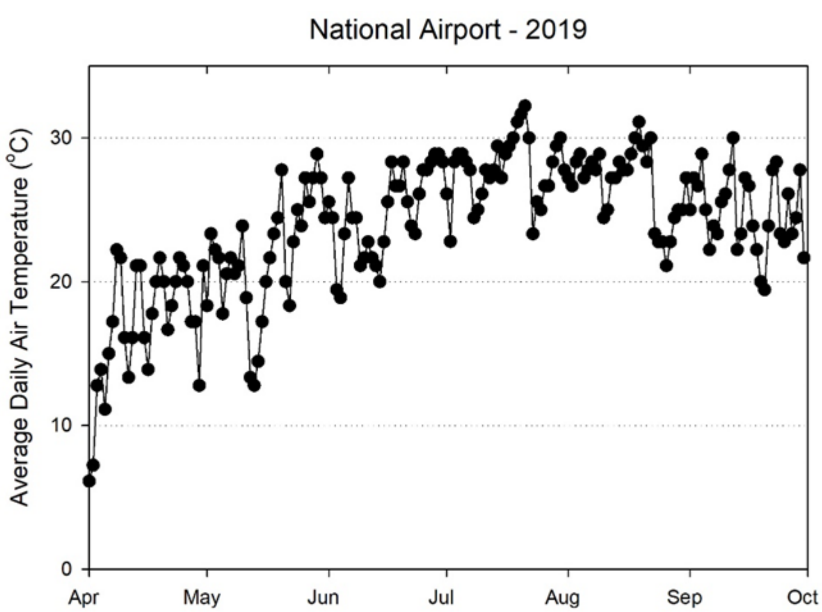
B. Physico-chemical Parameters – 2019



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 2019, water temperature followed the typical seasonal pattern at both sites with the exception of a marked cooling in mid-June that was most marked in the cove (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 study period, the two stations showed very similar water temperatures.



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.

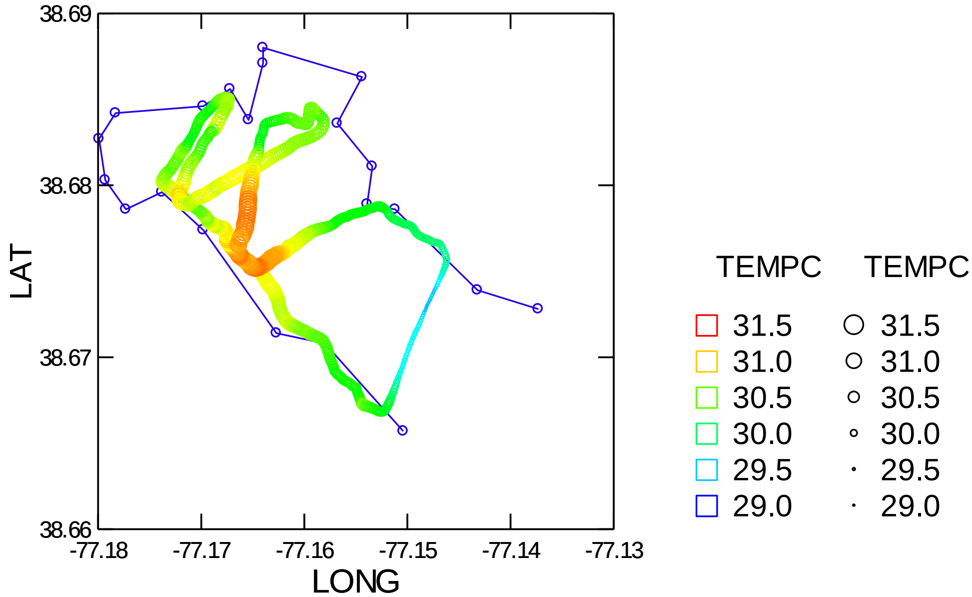


Figure 6. Temperature (ºC) observed in transects across Gunston Cove during data mapping cruise on August 21, 2019.

Temperature and Specific Conductance were measured during data mapping cruise on August 21, 2019 to assess spatial patterns in Gunston Cove. Temperature was lowest in the outer cove and highest along the south shore of the inner cove with values well above 31°C (Figure 6). Specific conductance 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.

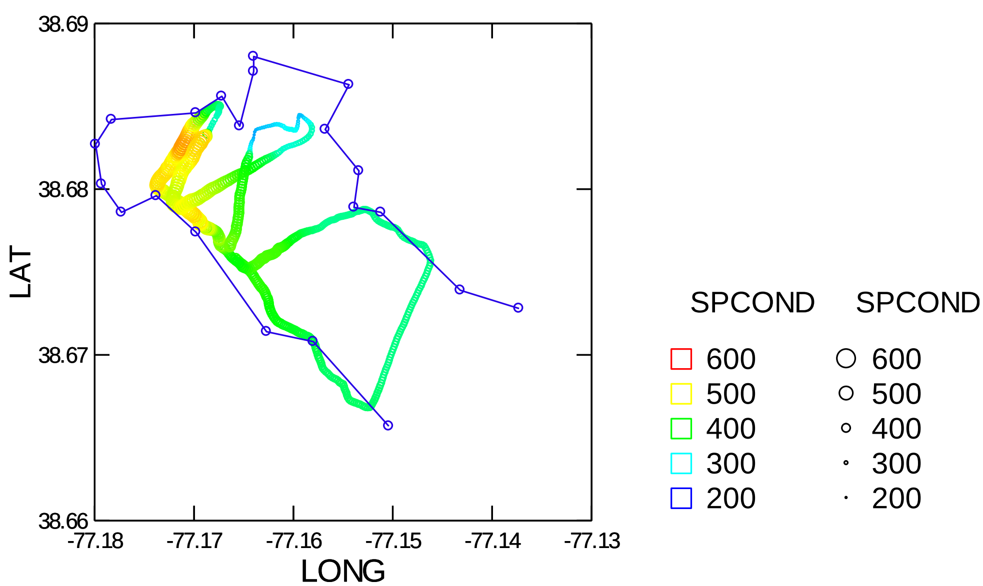
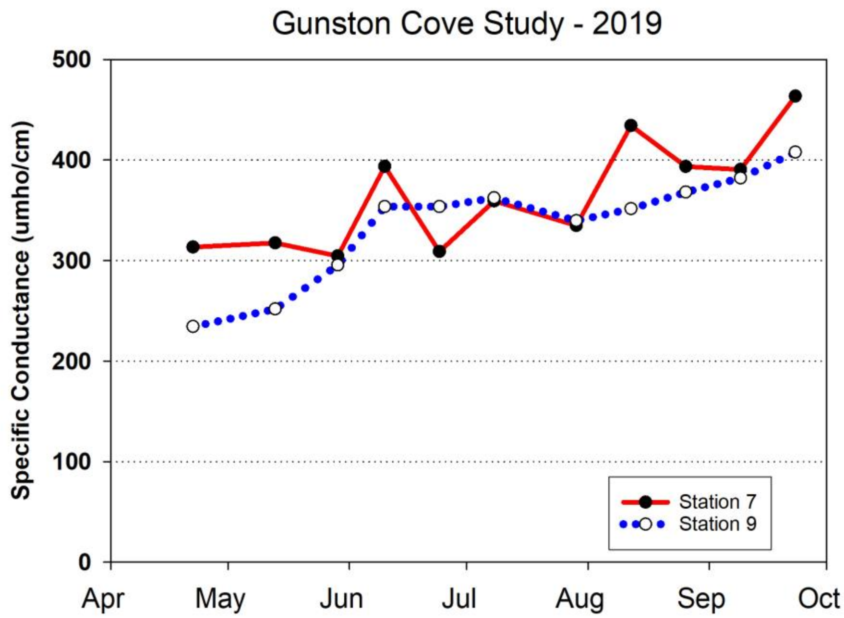


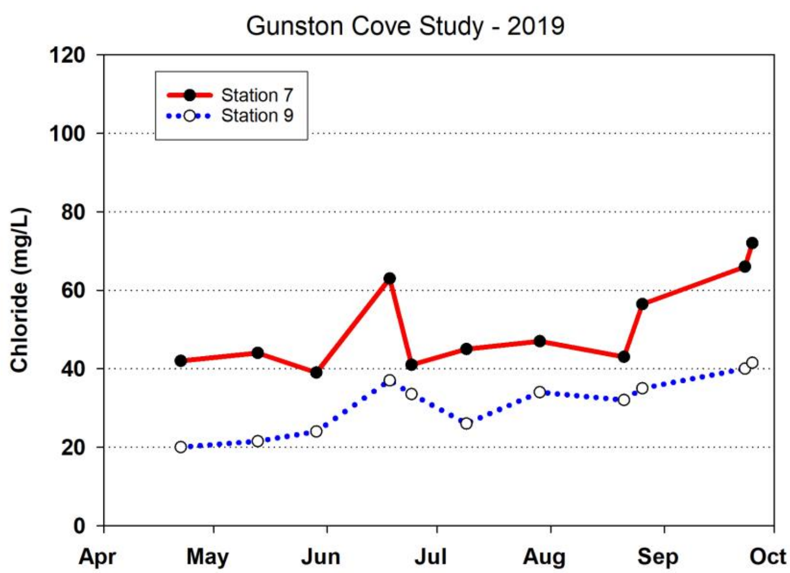
Figure 7. Specific Conductance (uS/cm) observed in transects across Gunston Cove during data mapping cruise on August 21, 2019.



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.

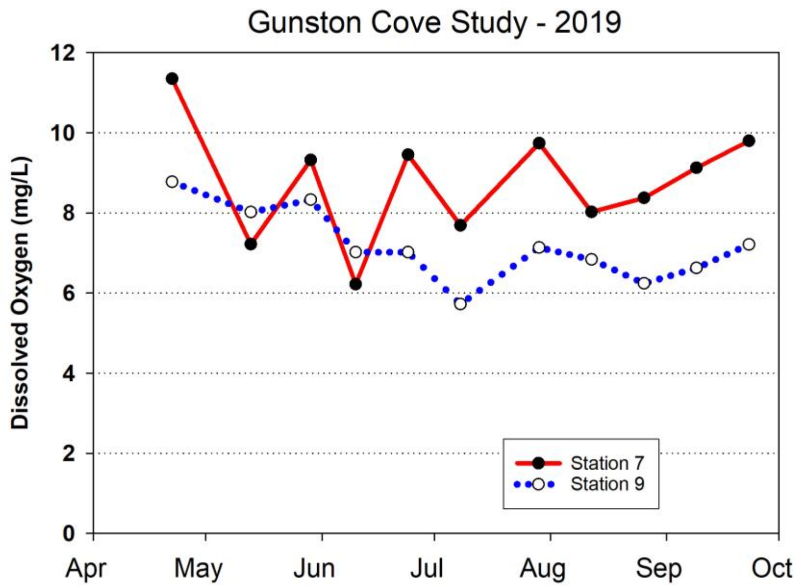
Figure 8. Specific Conductance (uS/cm). GMU Field Data. Month tick is at first day of month.

Specific conductance gradually increased through the study period at both stations (Figure 8). On some occasions values were higher in the cove than in the river. Chloride ion was markedly higher at Station 7 throughout the year, probably due to the Noman Cole effluent, but values were well within the freshwater range (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.

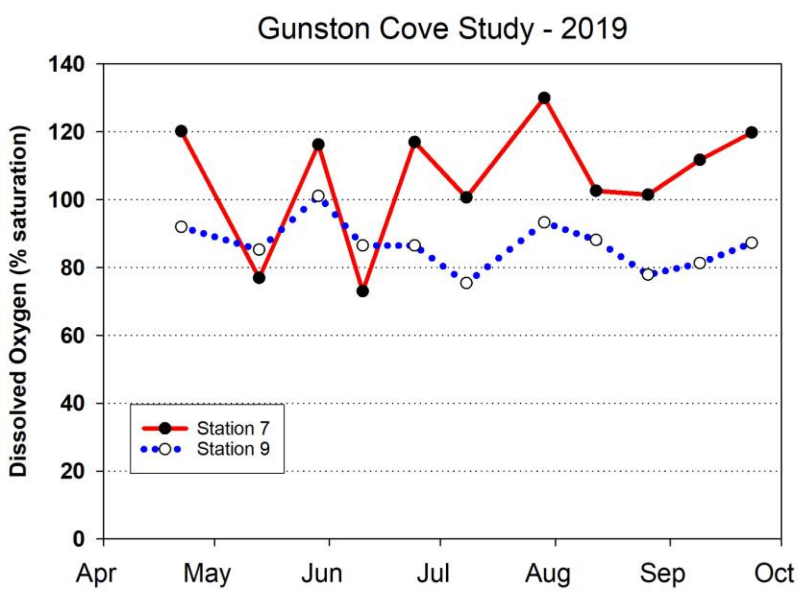
Figure 9. Chloride (mg/L). Fairfax County Lab Data. Month tick is at first day of month.



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 were observed in the cove in mid-May and mid-June.



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.

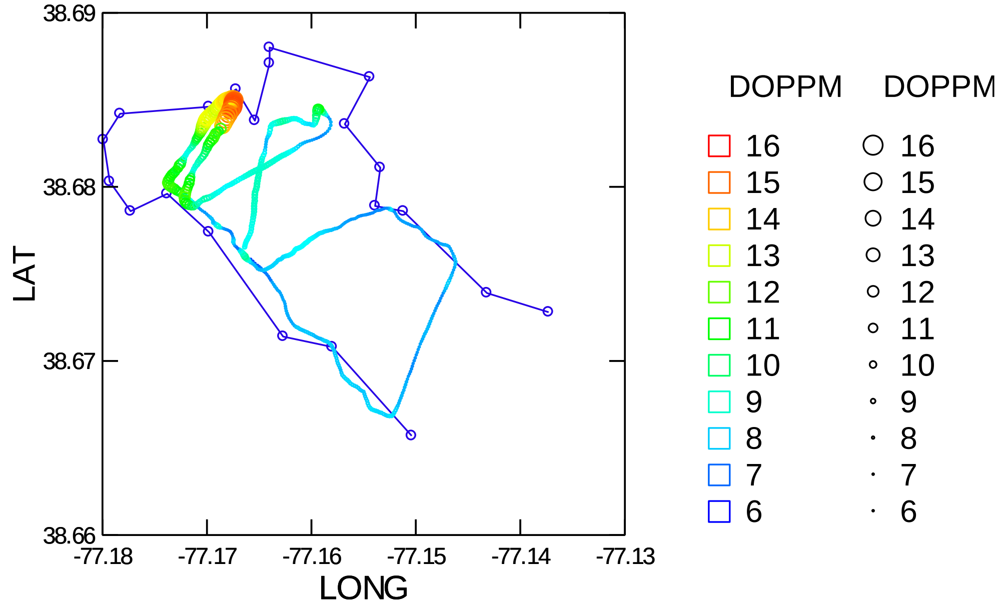


Figure 12. Dissolved Oxygen (mg/L) observed in transects across Gunston Cove during data mapping cruise on August 21, 2019.

Dissolved oxygen levels were highest in Pohick Bay, particularly along its north shore on August 21 (Figures 12&13). Values gradually decreased moving south east through the cove. The supersaturated DO values indicated strong photosynthetic activity in Pohick Bay, probably due to dense SAV there.

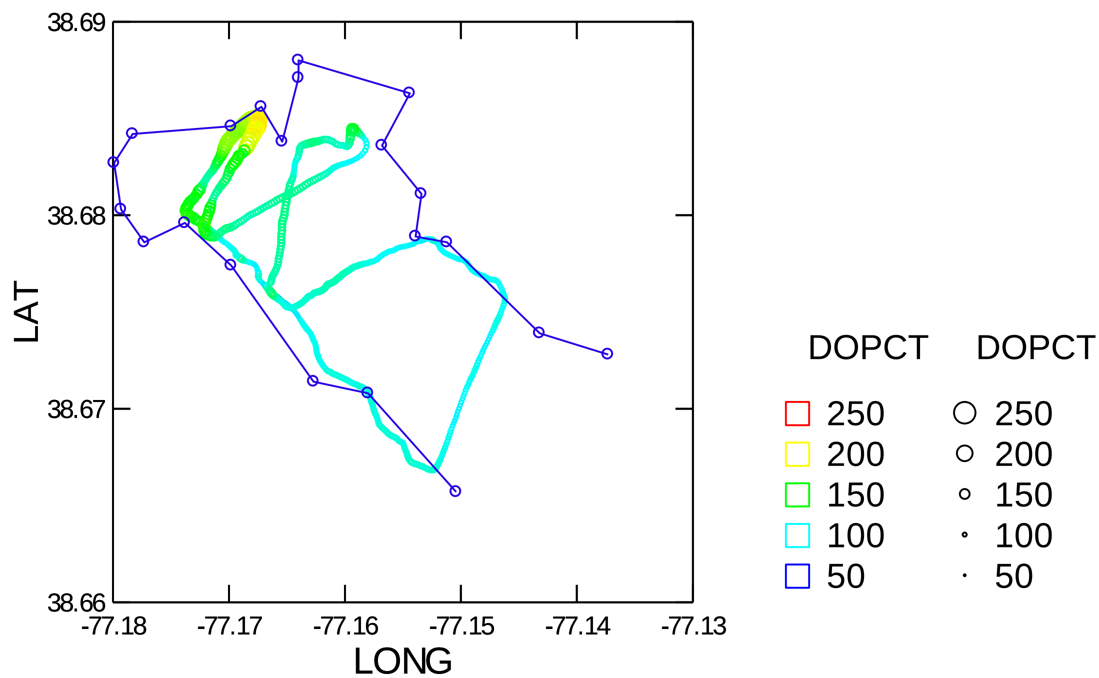
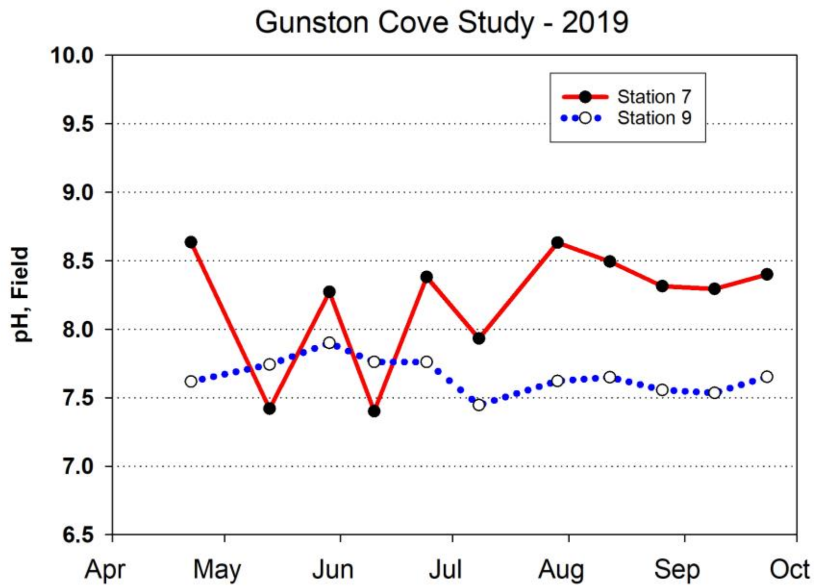


Figure 13. Dissolved Oxygen (% saturation) observed in transects across Gunston Cove during data mapping cruise on August 21, 2019.



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.

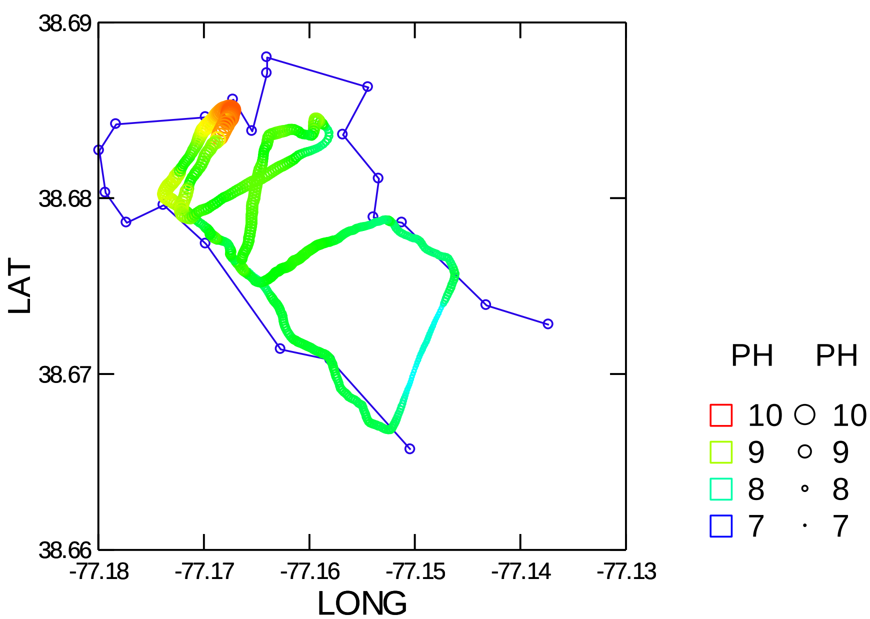
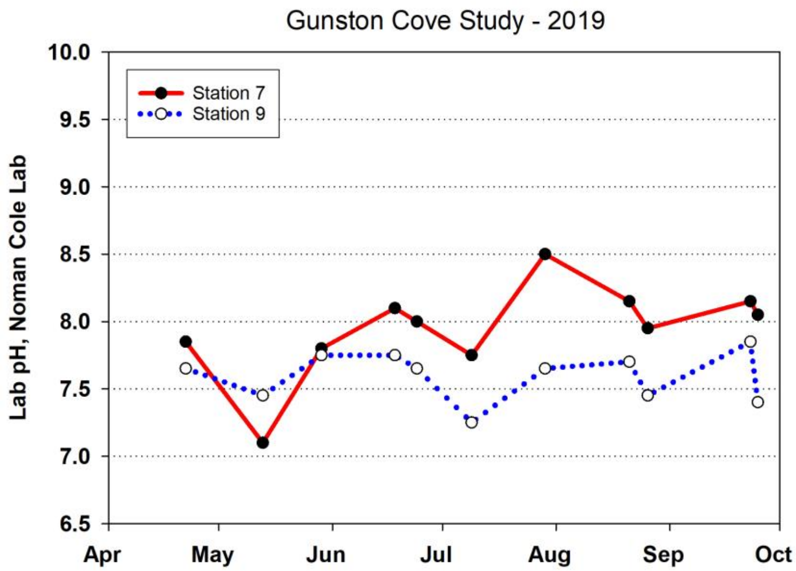


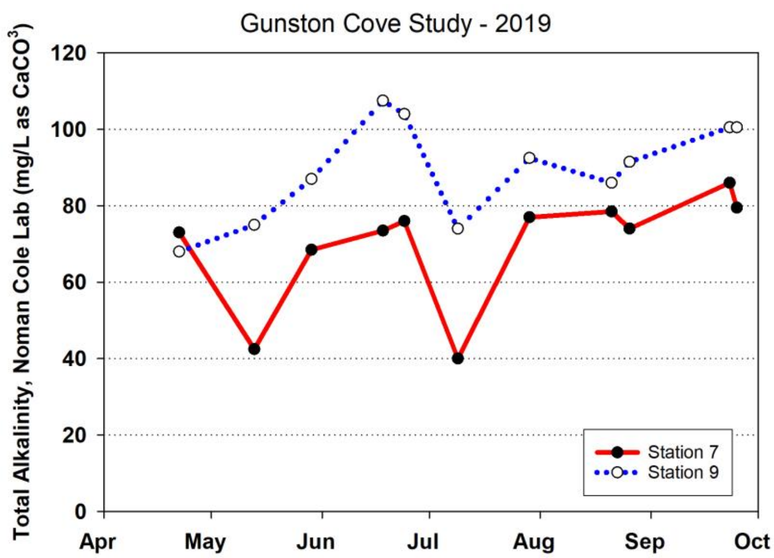
Figure 15. Field pH observed in transects across Gunston Cove during data mapping cruise on August 21, 2019.



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.

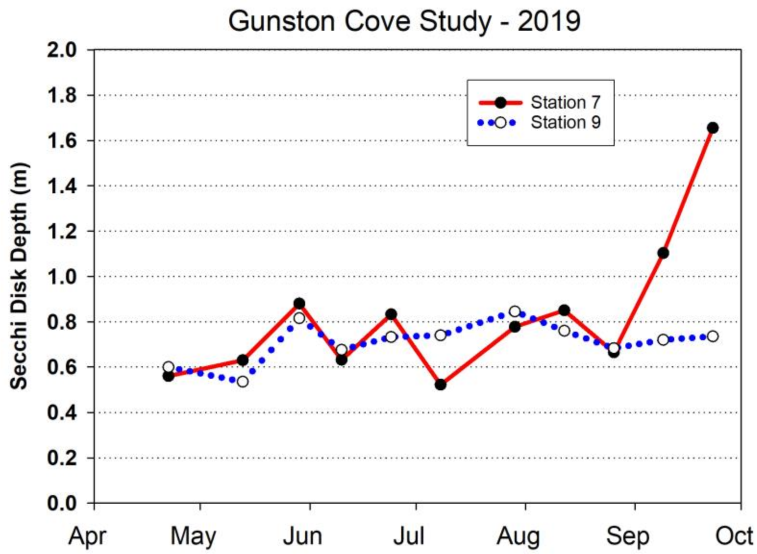
Figure 16. pH. Noman Cole Lab Data. Month tick is at first day of month.

Lab pH was collected less frequently, but generally showed similar patterns (Figure 16). Of note is that lab pH showed a major decrease in the cove in mid-May similar to pH and DO. Total alkalinity was consistently higher in the river than in the cove by about 10 units (Figure 17). There was some substantial seasonal variation in the cove with major declines in mid-May and early 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.

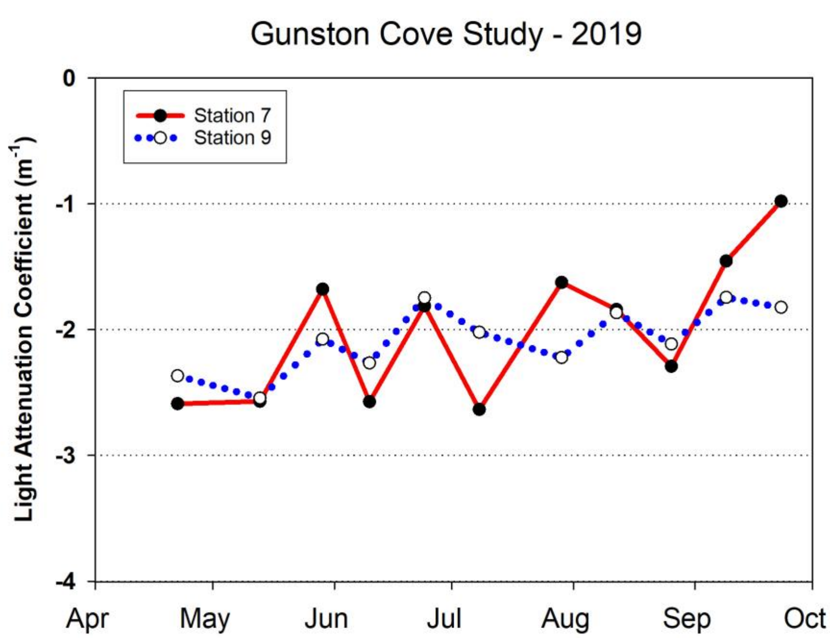
Figure 17. Total Alkalinity (mg/L as $CaCO_3$). Fairfax County Lab data. Month tick is at first day of month.



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.

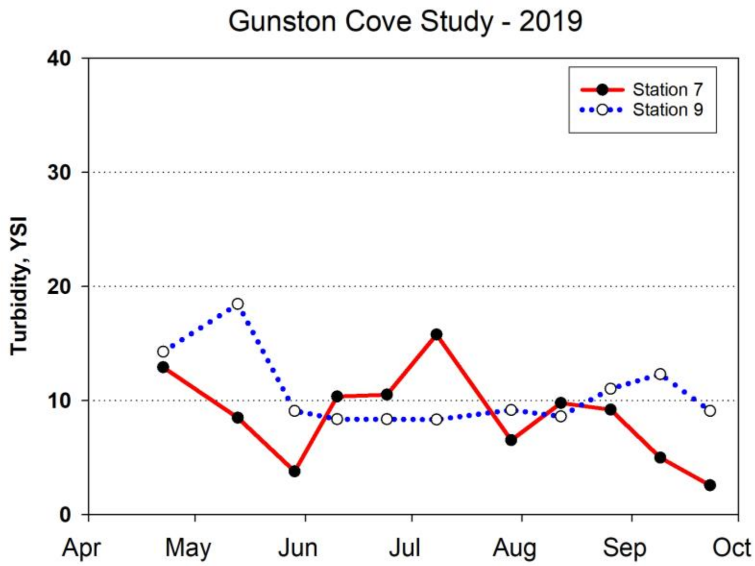
Figure 18. Secchi Disk Depth (m). GMU Field Data. Month tick is at first day of month.

Water clarity as reflected by Secchi disk transparency was fairly constant at both stations during 2019. Values hovered around 0.7 m for most of the year at both stations. The major exception was in September when water clarity increased greatly (Figure 18). Light attenuation coefficient exhibited a similar spatial and temporal pattern (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 exhibited patterns similar to Secchi with fairly constant values with a marked decrease in September in the cove (Figure 20). In the August datamapping cruise, turbidity was generally low except near the river where it was higher (Figure 21)..

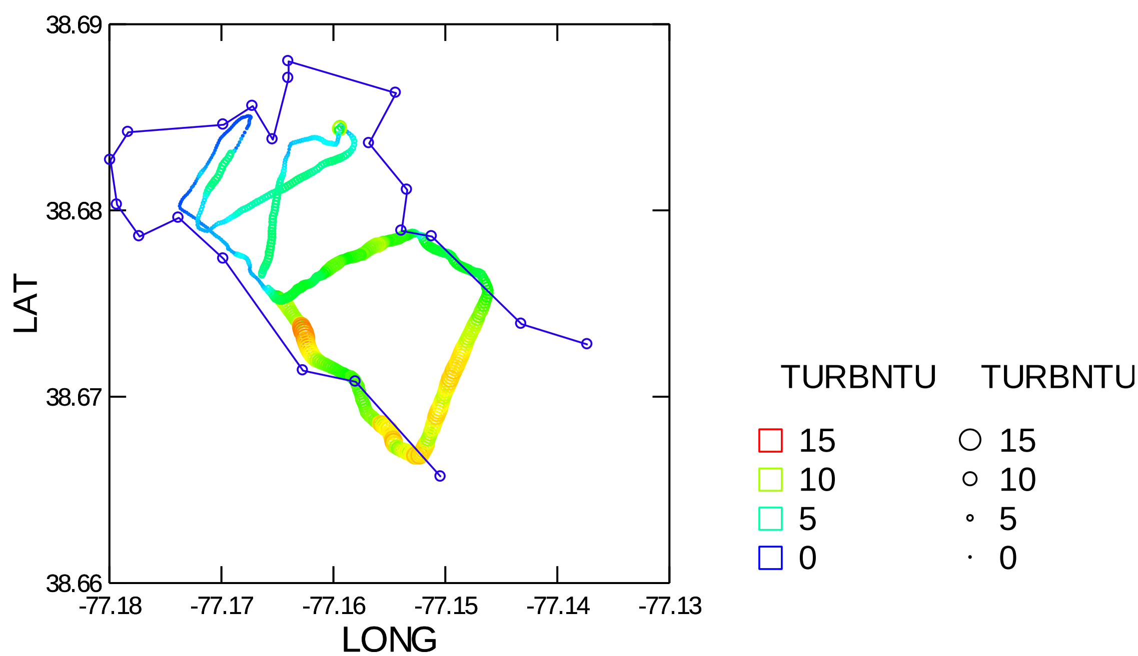
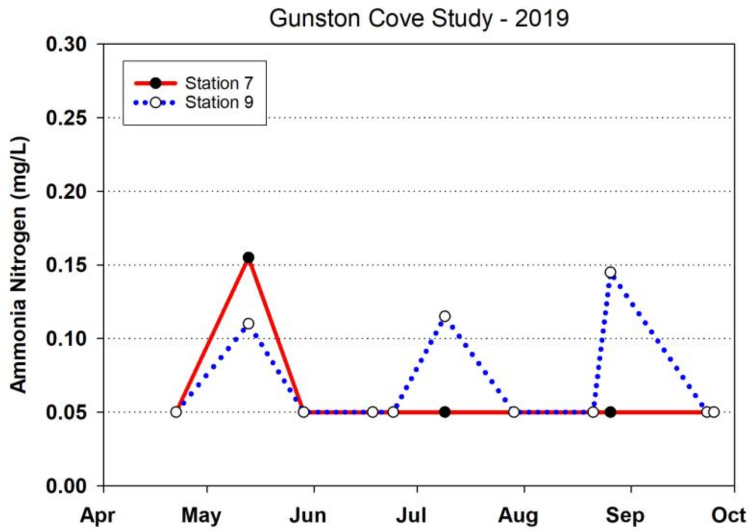


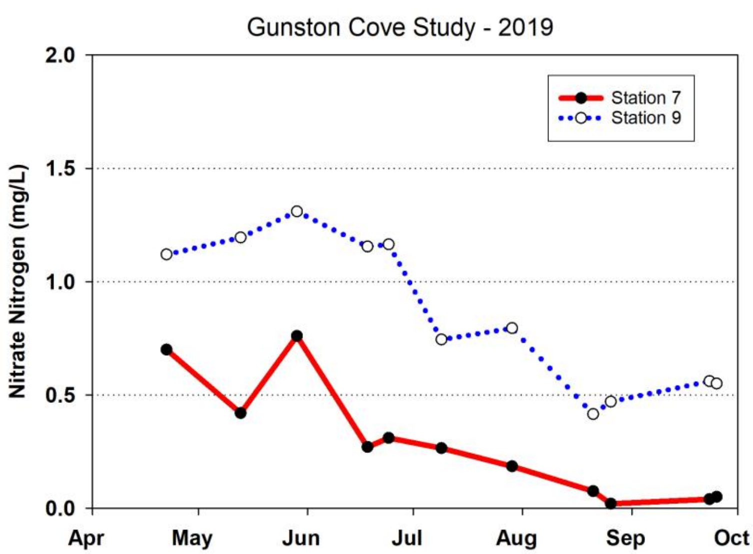
Figure 21. Turbidity (NTU) observed in transects across Gunston Cove during data mapping cruise on August 21, 2019.



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.

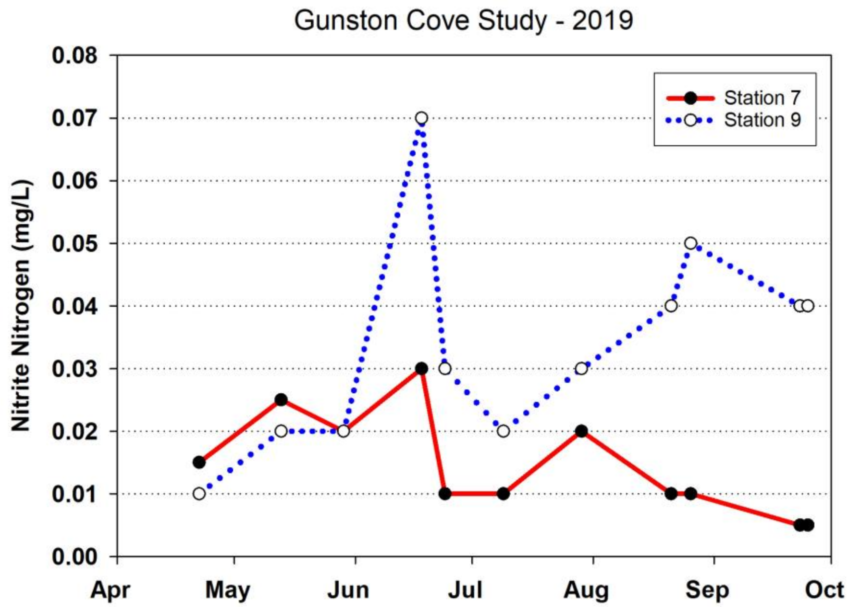
Figure 22. Ammonia Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection: 0.10 mg/L, LD values graphed as 0.05 mg/L)

Ammonia nitrogen was below detection limits in almost all samples reported in 2019 (Figure 22). Unfortunately, the detection limit at the Fairfax County Lab has increased substantially in the past several years from 0.01 mg/L to 0.1 mg/L. This has made it impossible to detect any further improvements in ammonia levels. GMU personnel ran ammonia nitrogen on sample splits from 23 Sept and recorded values of 0.021, 0.008, 0.028, and 0.037 mg/L for samples from Sta 7 Surface, Sta 7 Bottom, Sta 9 Surface, and Sta 9 Bottom respectively. These are consistent with the <0.1 mg/L values reported by Noman Cole. Nitrate nitrogen levels were consistently higher in the river than in the cove (Figure 23). A clear seasonal decline was observed as in most previous years.



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.

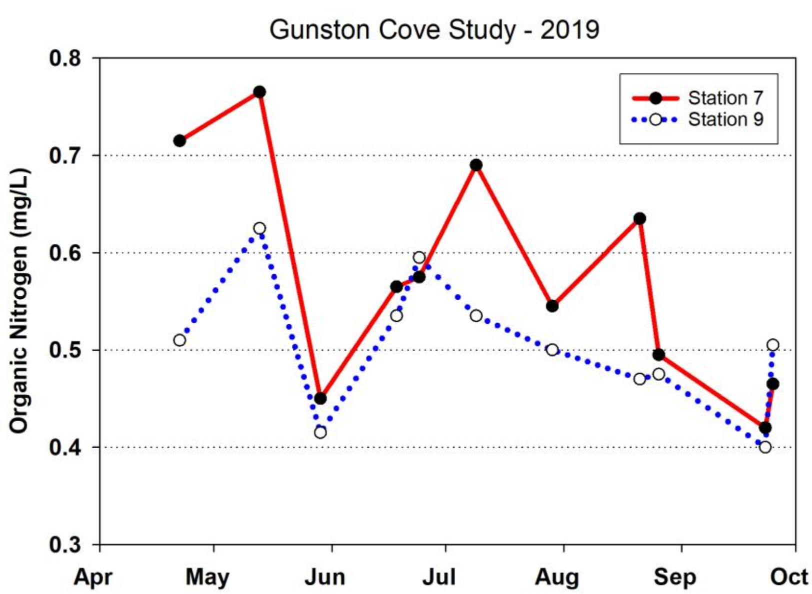
Figure 23. Nitrate Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection: 0.01 mg/L; LD values graphed as 0.005 mg/L)



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.

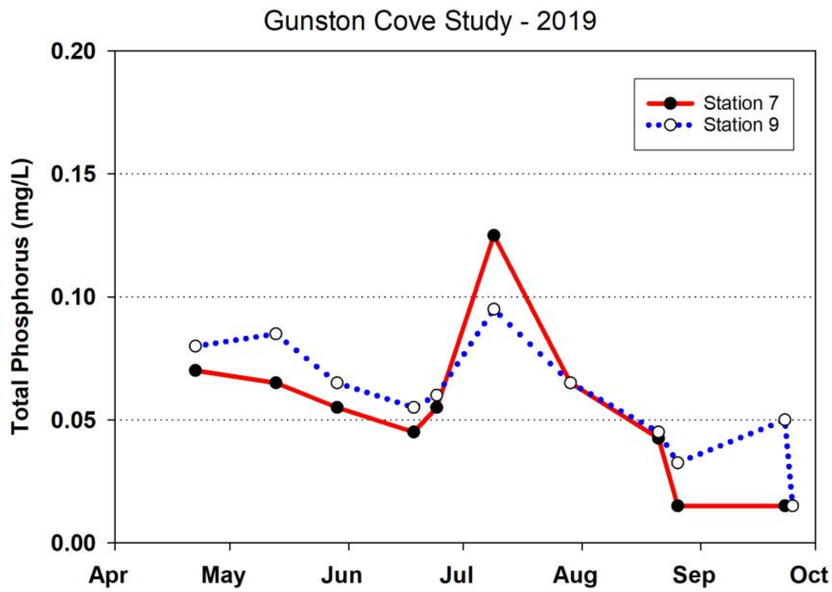
Figure 24. Nitrite Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (limit of detection = 0.01 mg/L).

Nitrite nitrogen was low and quite variable, but higher in the summer and fall in the river (Figure 24). Organic nitrogen was quite variable at both stations. Generally the cove was higher than the river (Figure 25).



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.

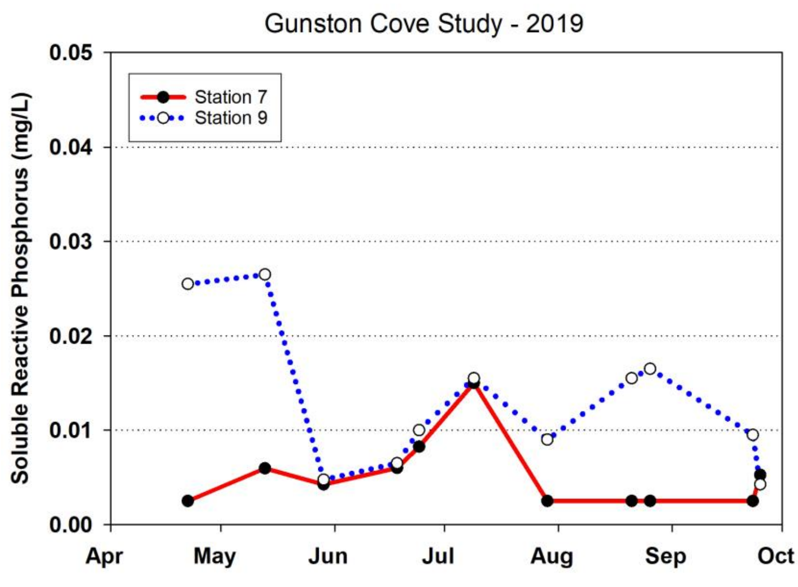
Figure 25. Organic Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month.



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.

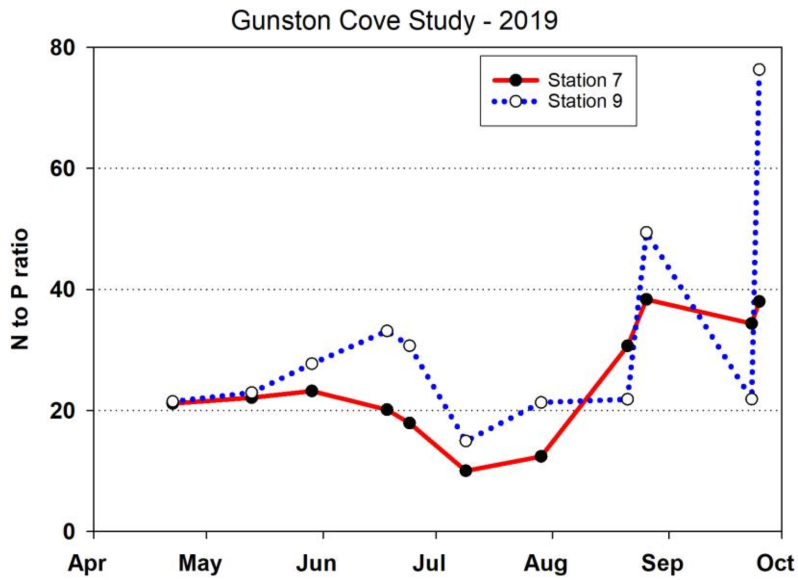
Figure 26. Total Phosphorus (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection: 0.03 mg/L)

Total phosphorus was similar at both sites on almost all dates and showed a general downward trend except for a marked increase in July (Figure 26). Soluble reactive phosphorus was consistently higher in the river (Figure 27). Both stations had an increase in July at the same time as the total P increase.



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.

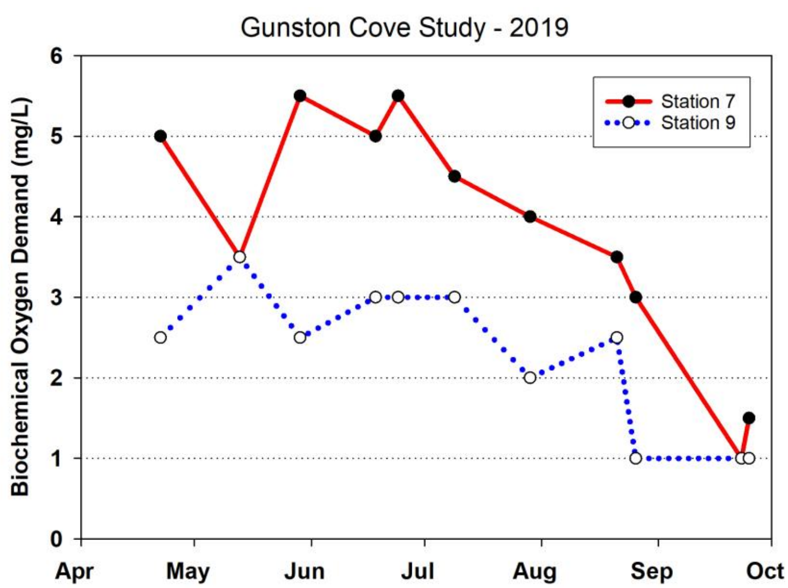
Figure 27. Soluble Reactive Phosphorus (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection = 0.005 mg/L)



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.

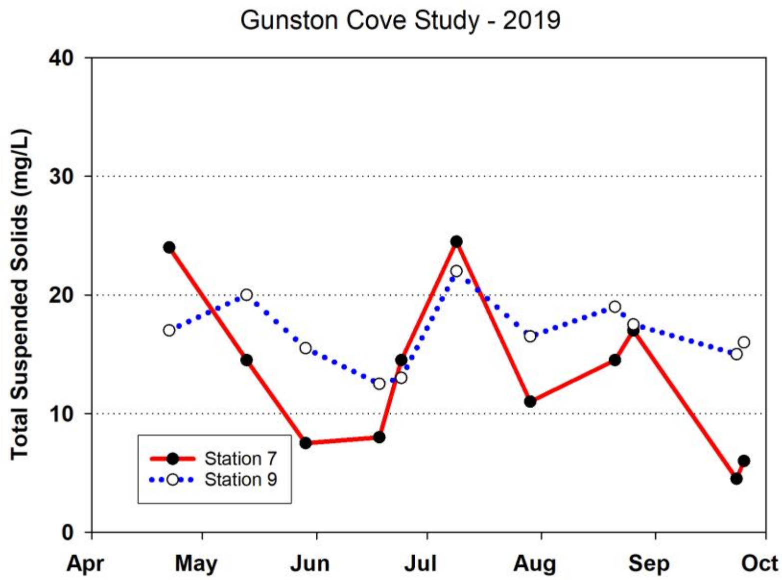
Figure 28. N/P Ratio (by mass). Fairfax County Lab Data. Month tick is at first day of month.

N/P ratio exhibited little consistent seasonal pattern at either site (Figure 28). Values bottomed out at about 10 in late July in the cove approaching N limitation. Values in the river remained consistently above 17 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

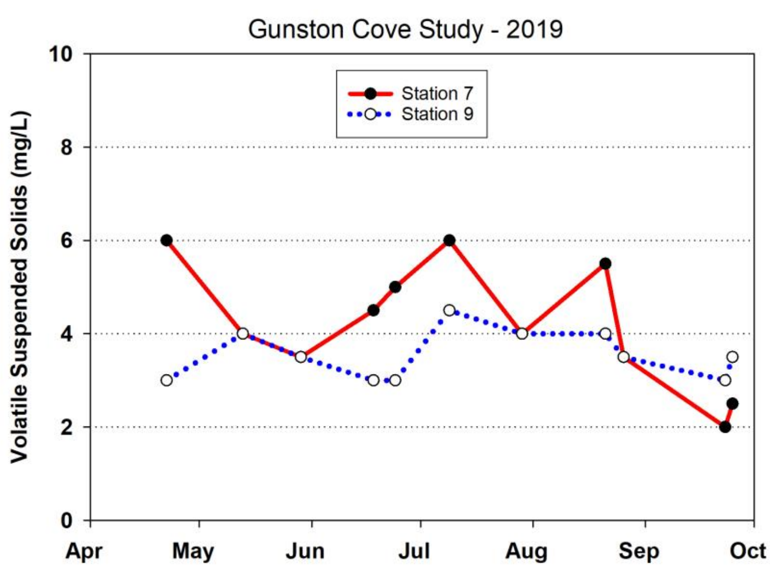
Figure 29. Biochemical Oxygen Demand (mg/L). Fairfax County Lab Data. Month tick is at first day of month.



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.

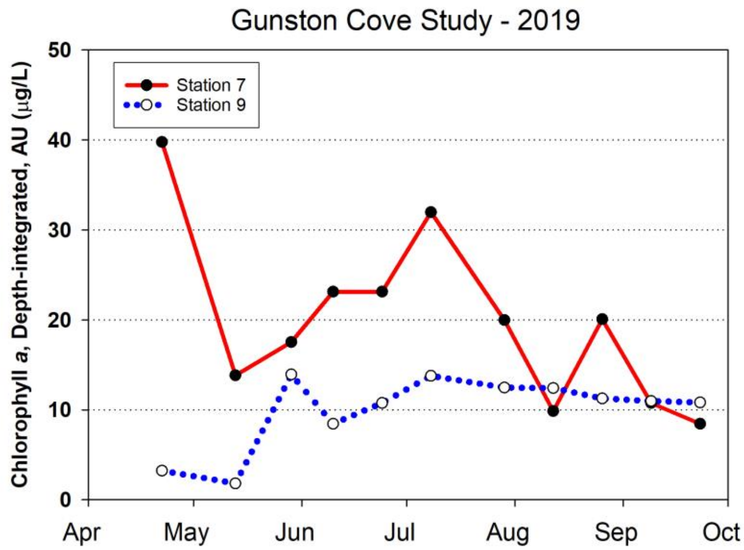
Total suspended solids was fairly constant in the river, but more variable in the cove (Figure 30). Noteworthy were low value in the cove in late May/June and September and the high value in July. Volatile suspended solids was less variable (Figure 31).



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.

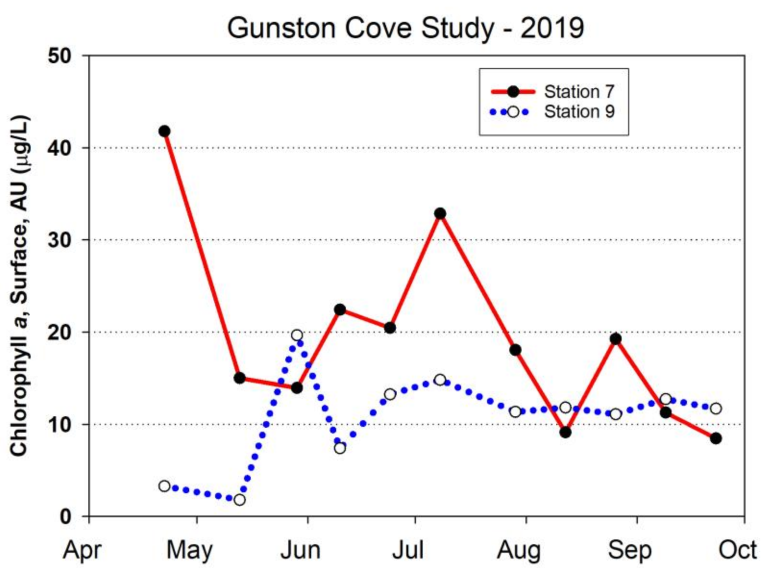
C. Phytoplankton -2019



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. AU soak procedure.

Chlorophyll *a* at in the cove was highest in April exceeding 40 µg/L (Figures 32&33). It decreased substantially in May and then built back up to a mid-summer maximum of 33 µg/L in early July. Values mostly declined through the remainder of the year. Depth-integrated and surface chlorophyll showed similar spatial and temporal patterns.



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. AU soak procedure.

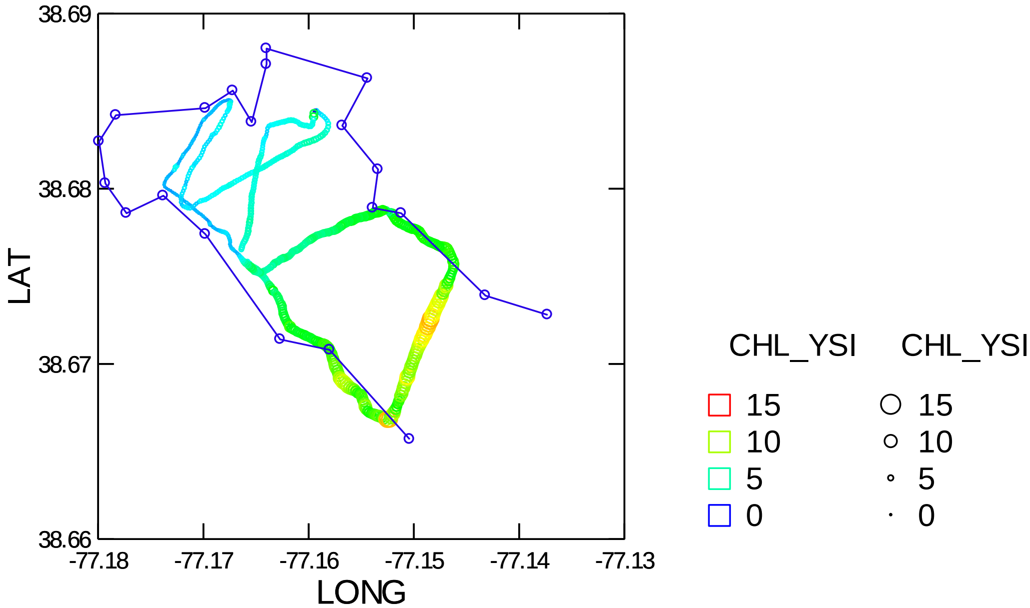


Figure 34. Chlorophyll *a* (µg/L) observed in transects across Gunston Cove during data mapping cruise on August 21, 2019.

Chlorophyll data from the datamapping cruise in 2019 showed a pattern that was different from DO and pH with higher values in the outer part of Gunston Cove (Figure 34). In contrast to the strong positive correlation between chlorophyll and dissolved oxygen in 2018, there was a significant negative correlation between the two variables in 2019 indicating that phytoplankton were not driving DO (Figure 35). The other potential driver of DO, SAV, was highly depressed in 2018, but made a strong comeback in 2019. SAV depresses phytoplankton chlorophyll. Thus, the high DO values in 2019 can be attributed to SAV photosynthesis.

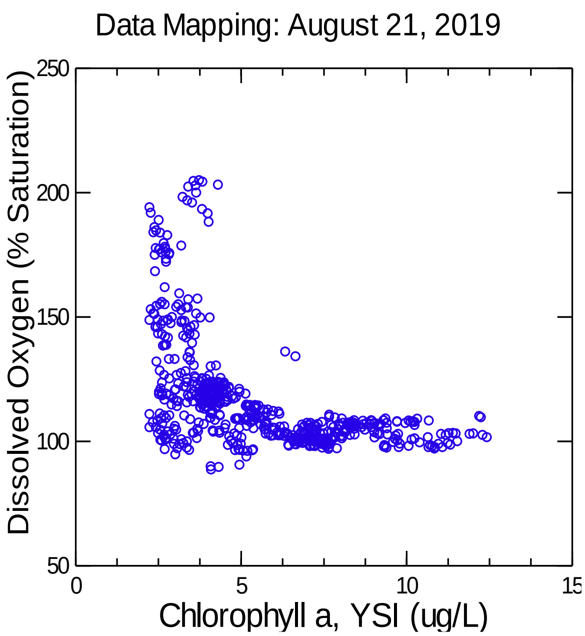
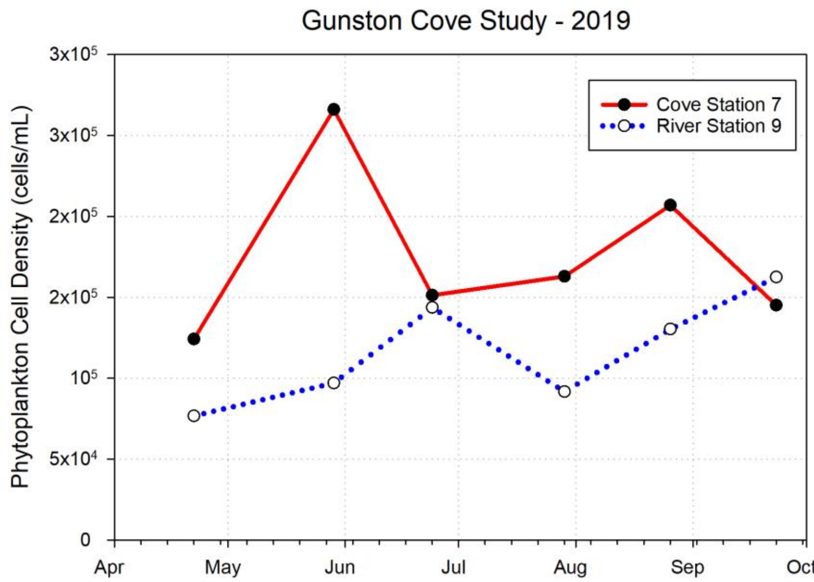


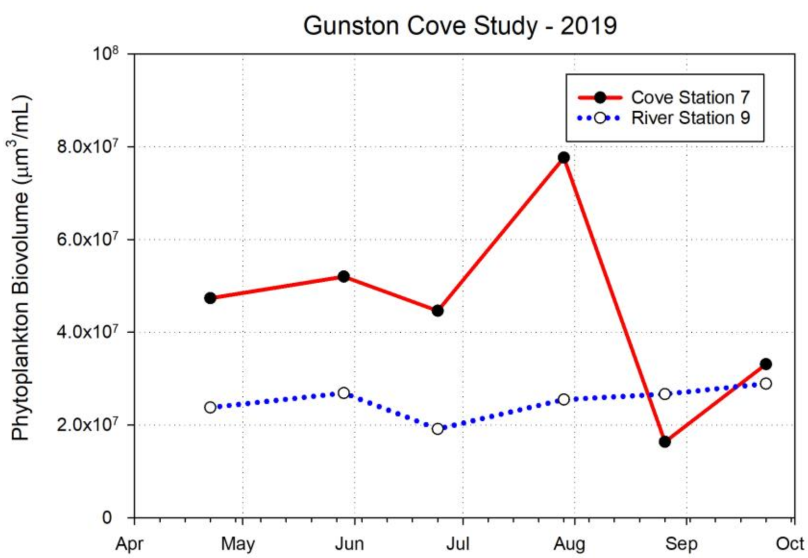
Figure 35. Scatterplot showing the negative correlation between Chlorophyll *a* and Dissolved Oxygen in Gunston Cove as derived from the datamapping cruise. (r=-0.529, n=580)



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.

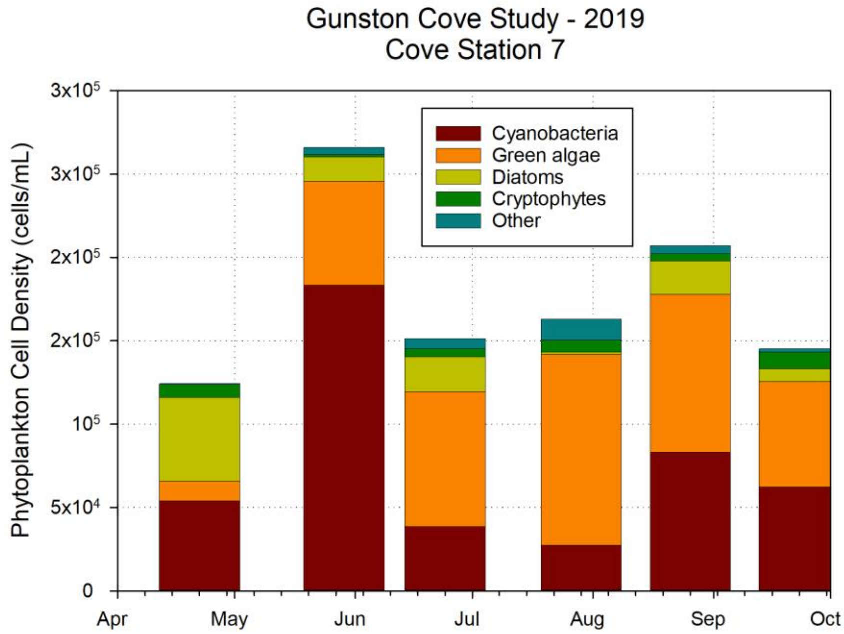
Figure 36. Phytoplankton Density (cells/mL).

In the cove phytoplankton density was low in April and increased in May, while in the river there was a gradual increase from April through June (Figure 36). This was followed by a gradual rise into late August. Cove values were consistently higher than river values through late July, but were similar in August and September (Figure 37).



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.

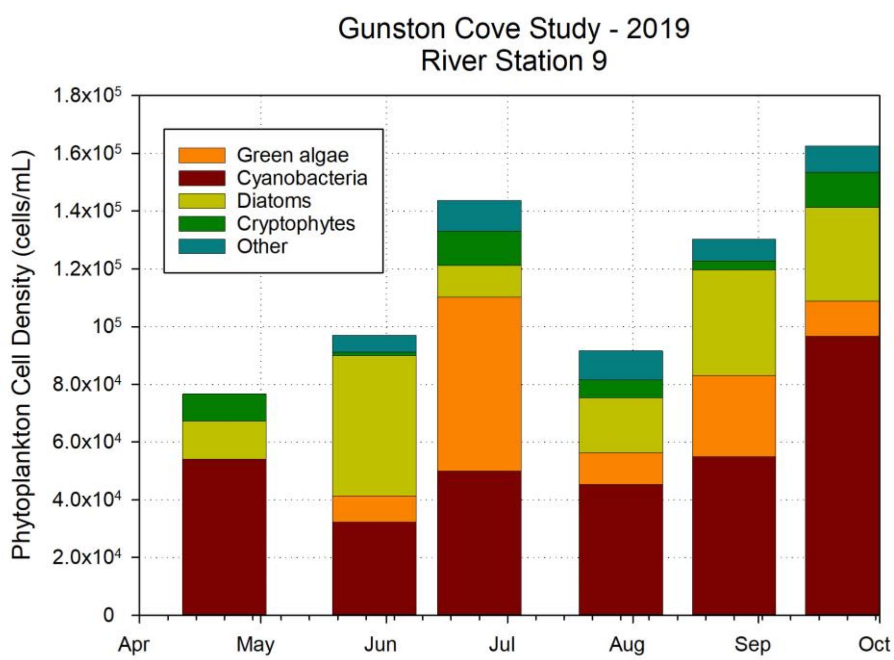
Figure 37. Phytoplankton Biovolume (um^3/mL).



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.

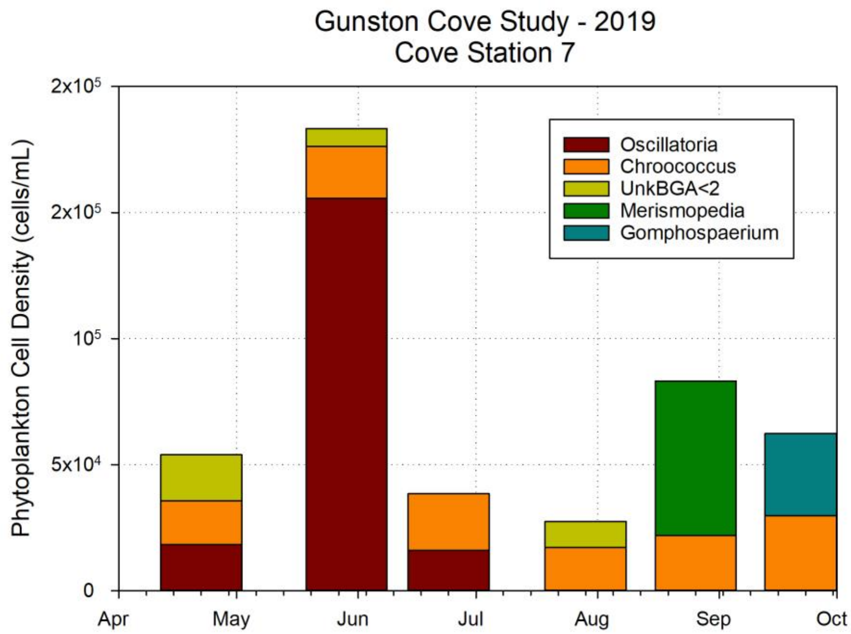
Figure 38. Phytoplankton Density by Major Group (cells/mL). Gunston Cove.

In 2019 phytoplankton density in the cove was dominated by cyanobacteria and diatoms in April with green algae becoming more important for the rest of the year (Figure 38). In the river dominance shifted from cyanobacteria to diatoms to green algae over the spring and early summer period with cyanobacteria becoming more dominant from late July on (Figure 39).



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

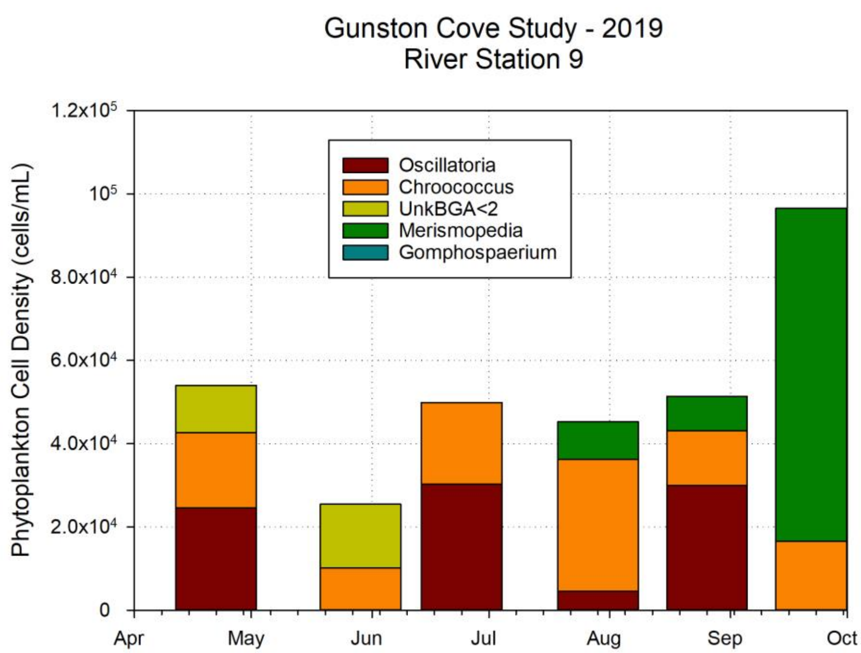
Oscillatoria – a filament with cylindrical cells

An unknown unicellular cyanobacterium less than 2 *u*

Chroococcus – individual spherical cells

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

Oscillatoria was the most abundant cyanobacterium in the cove early in the year. *Chroococcus* present on all dates (Figure 40). In the river *Oscillatoria* was dominant in April, June, and September (Figure 41). Chroococcus and unknown cyanobacterium were dominant in May. *Merismopedia* was dominant in September.



Anabaena

Microcystis

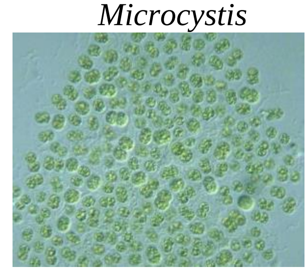
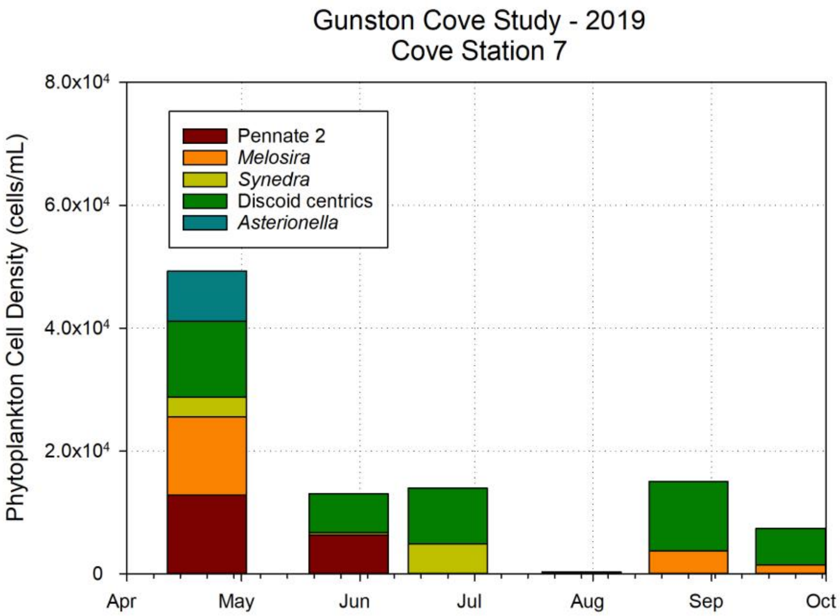


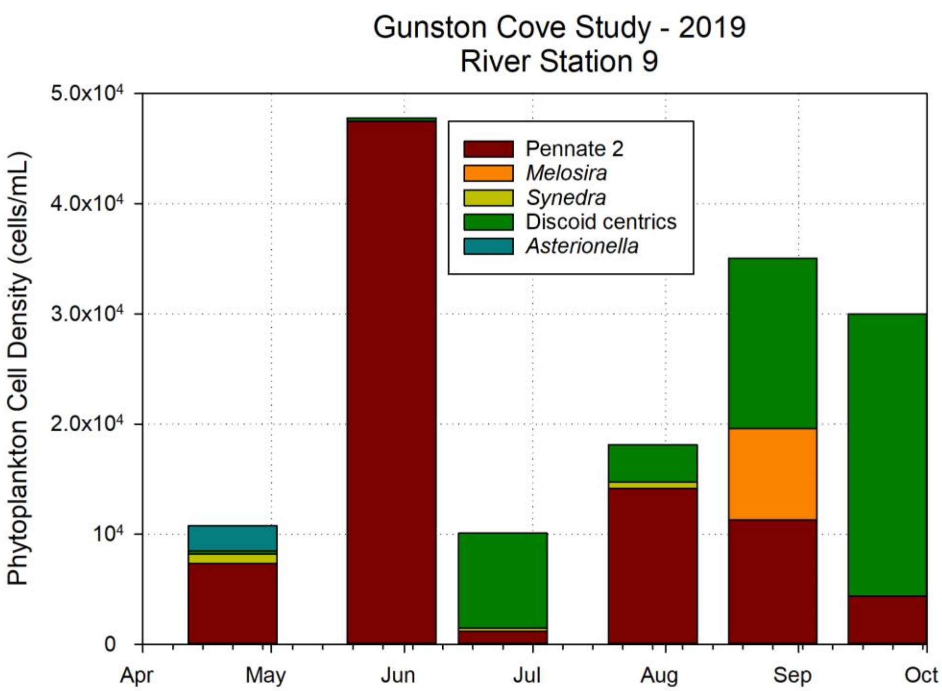
Figure 41. Phytoplankton Density by Dominant Cyanobacteria (cells/mL). River.



The most numerous diatoms in the phytoplankton were:
- *Melosira* – a filamentous centric diatom
- Centrics – discoid centric diatoms
- Pennate 2 – a small pinnate diatom
- *Synedra* – a pinnate diatom
- *Asterionella* – a small pennate diatom that forms spoked - wheel colony

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

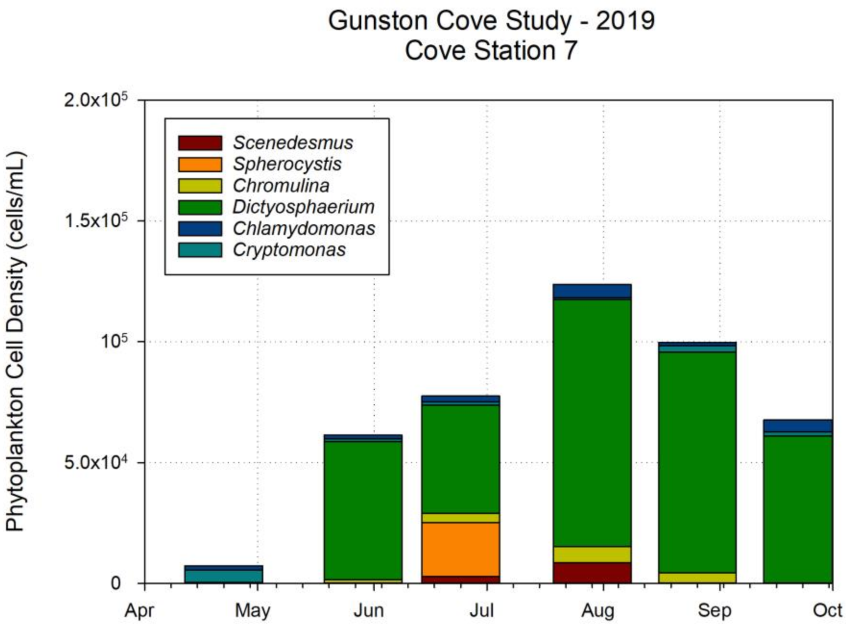
Diatom cell density in April in the cove was composed of a diverse array of taxa (Figure 42). Discoid centrics were almost always important. In the river Pennate 2 was dominant in April and May while discoid centrics were most important for the rest of the year (Figure 43). The normally dominant *Melosira* was not as abundant in 2019 as in most years.



Melosira

Discoid Centrics

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

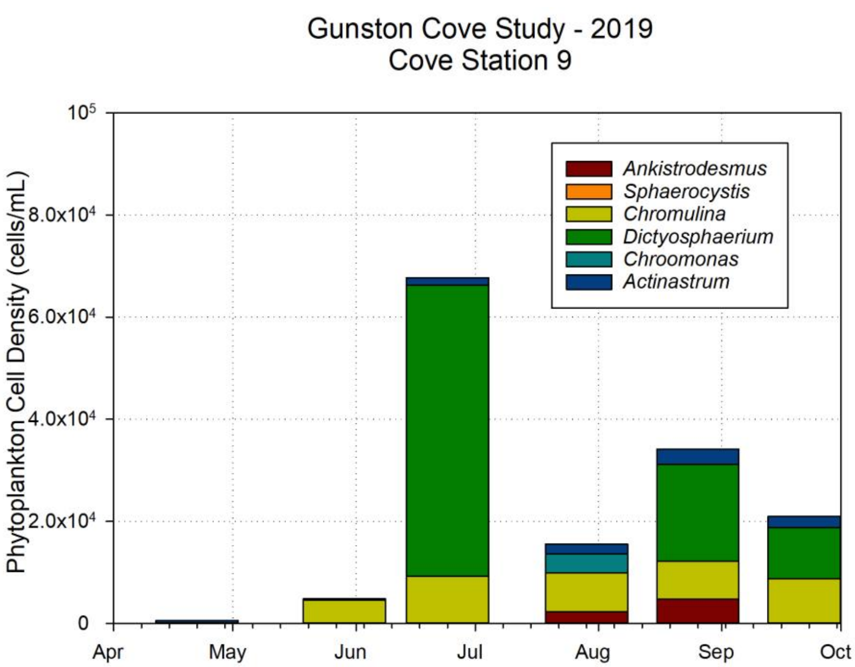


The most numerous phytoplankton among the cryptophytes, green algae and others were:

- *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.

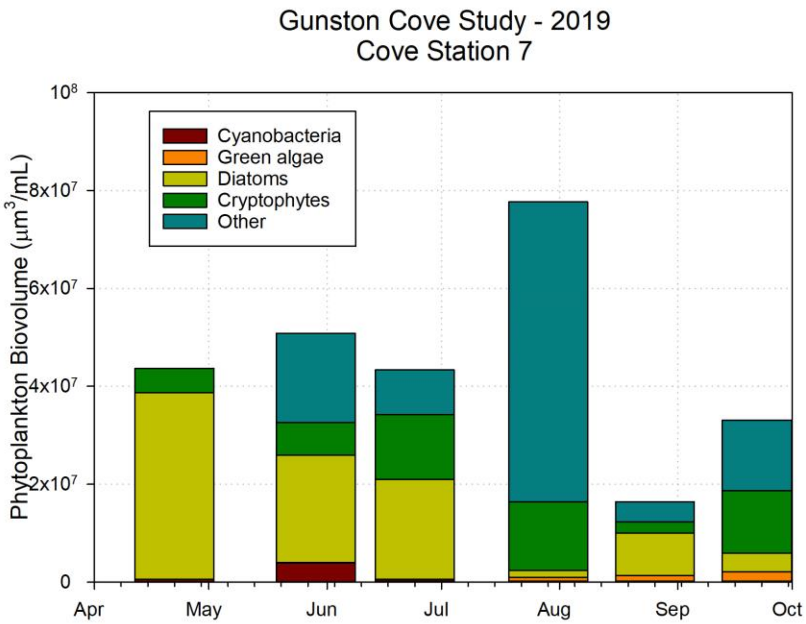
In the cove a number of other taxa were important, but the green alga *Dictyosphaerium* stood out on all dates (Figure 44). In the river *Dictyosphaerium* was very prominent in June and Chromulina was present on almost all dates (Figure 45).



Cryptomonas

Scenedesmus

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

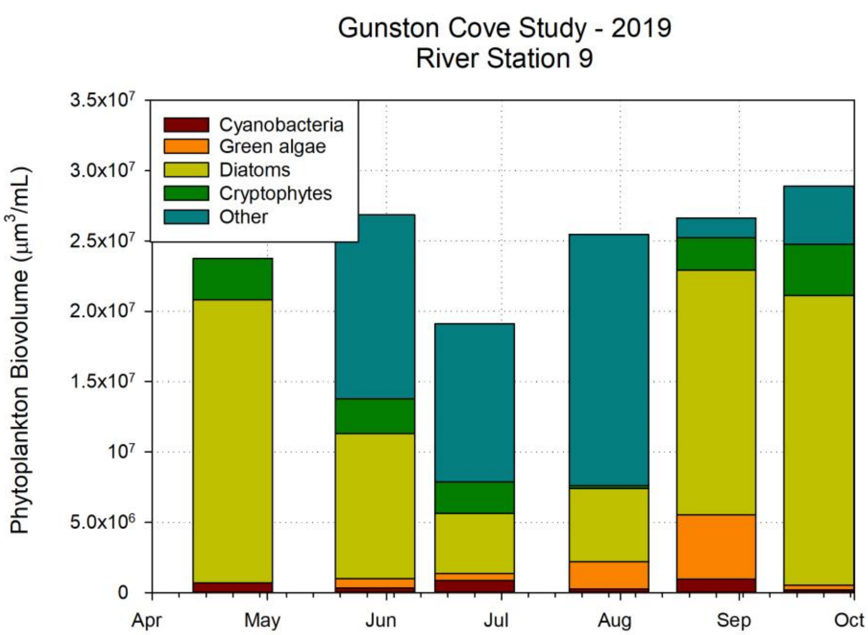


Total phytoplankton biovolume can be broken down into groups:

- **Cyanobacteria** ("blue-green" algae)
- **Green algae**
- **Diatoms** – includes both centric and pinnate
- **Cryptophytes**
- **Other** – includes euglenoids, chrysophytes, and dinoflagellates

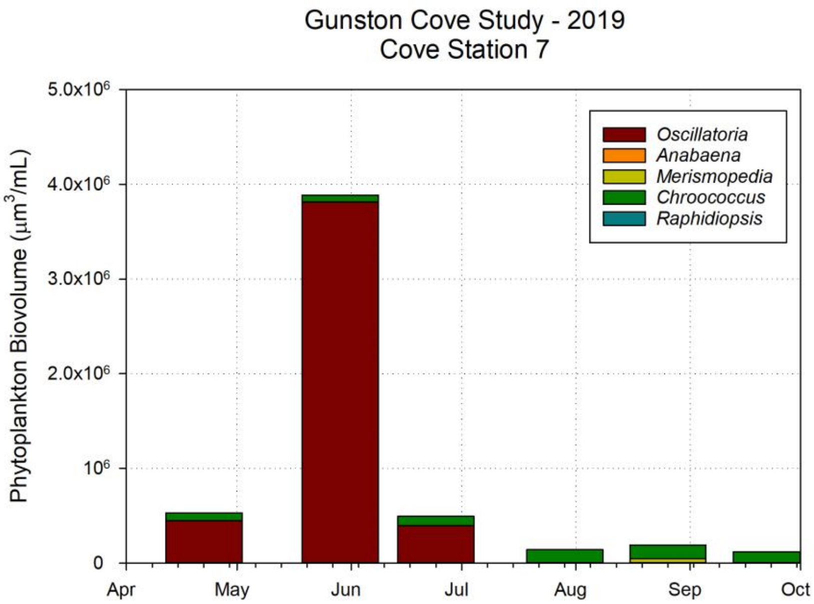
Figure 46. Phytoplankton Biovolume (um^3/mL) by Major Groups. Gunston Cove.

In the cove biovolume was strongly dominated by diatoms from April to July (Figure 46). Other algae led by euglenoids stood out in August. In the river, diatoms were dominant in biovolume in April, August, and September, but in May, June, and July other algae were most abundant (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.

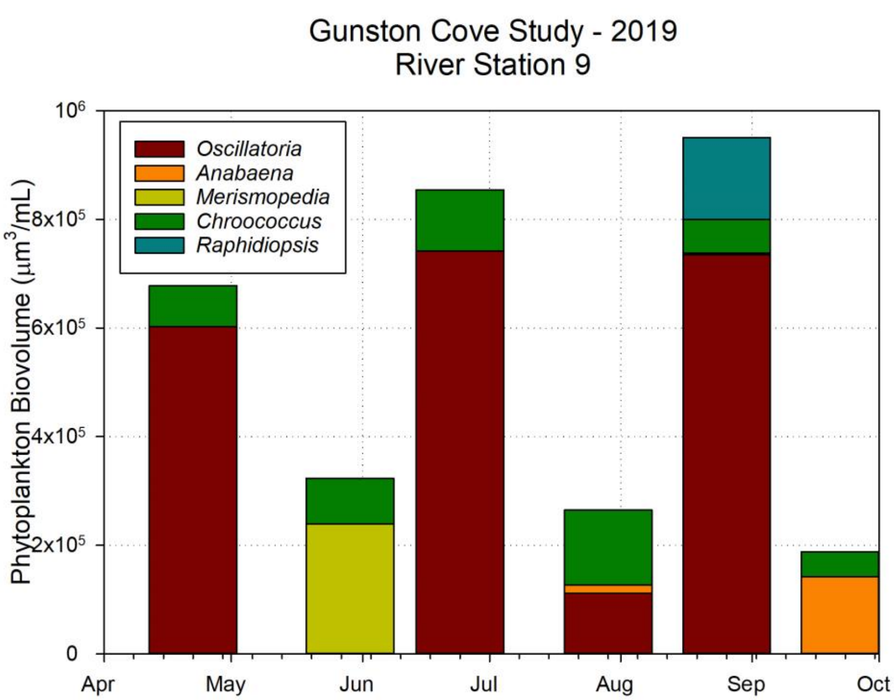
Figure 47. Phytoplankton Biovolume (um^3/mL) by Major Groups. River.



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 and was particularly abundant in late May (Figure 48). In the river *Oscillatoria* was often highly dominant (Figure 49).



Oscillatoria

Chroococcus

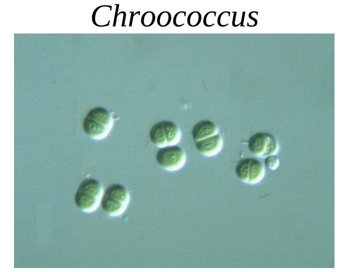
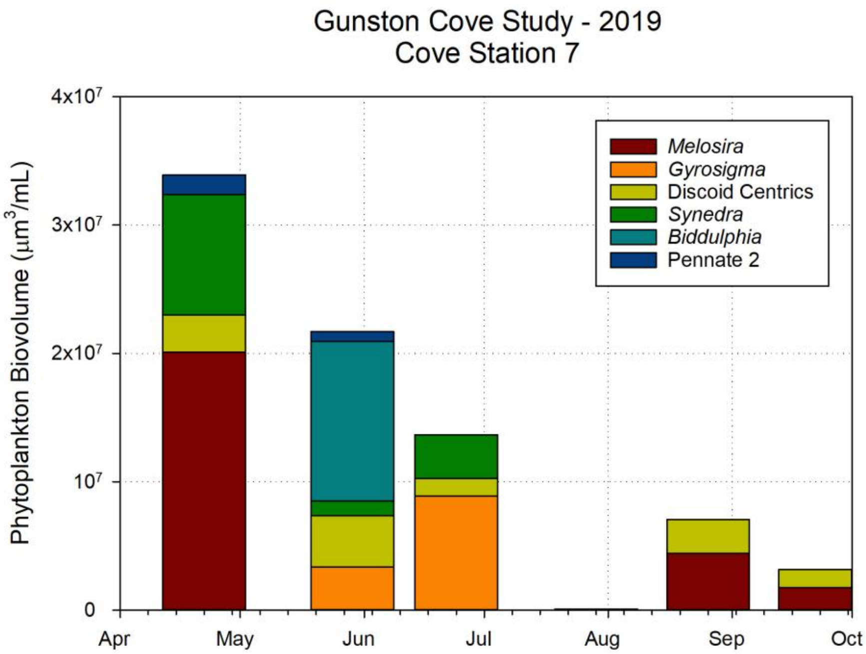


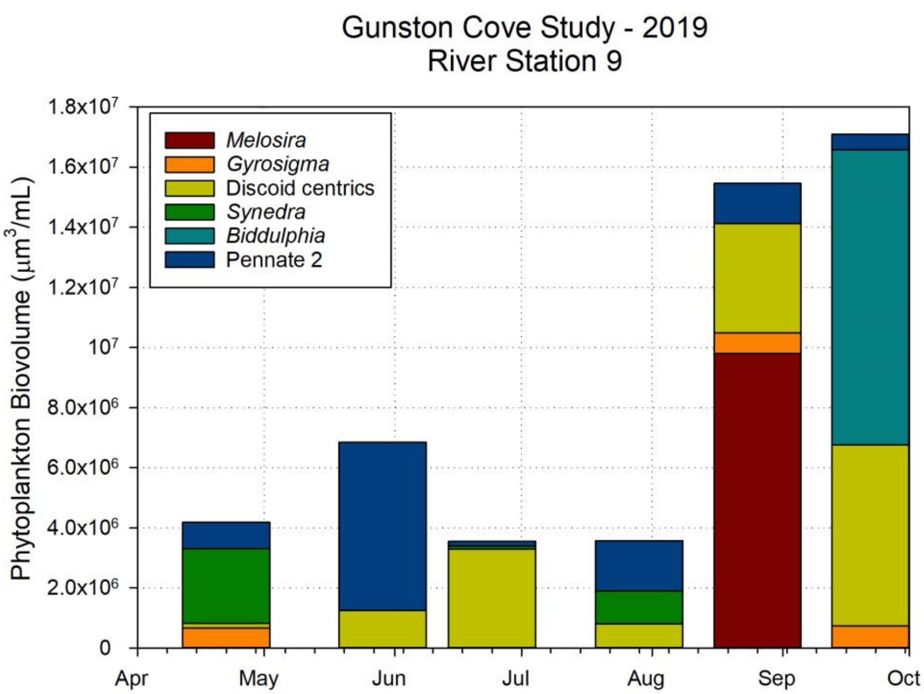
Figure 49. Phytoplankton Biovolume (um^3/mL) by Cyanobacterial Taxa. River.



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 (um³/mL) by Diatom Taxa. Gunston Cove.

In the cove *Melosira* was dominant in April, but other taxa were more common in May and June (Figure 50). In the river the *Melosira* dominance was restricted to late August, while discoid centrics were important on most dates (Figure 51).



Melosira

Surirella

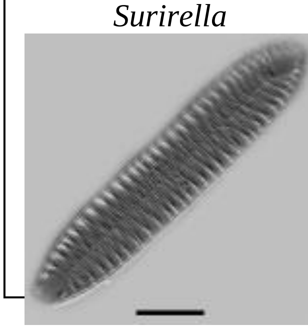
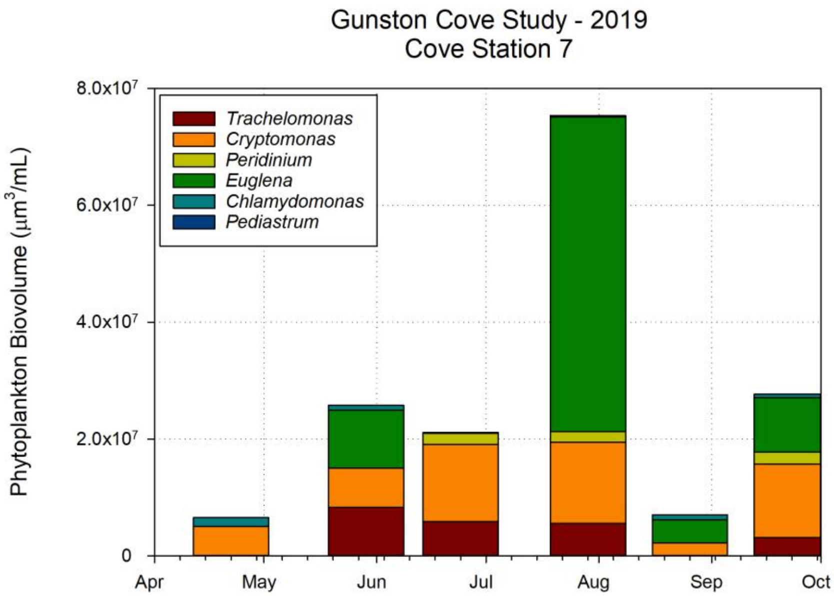


Figure 51. Phytoplankton Biovolume (um³/mL) by Diatom Taxa. River.

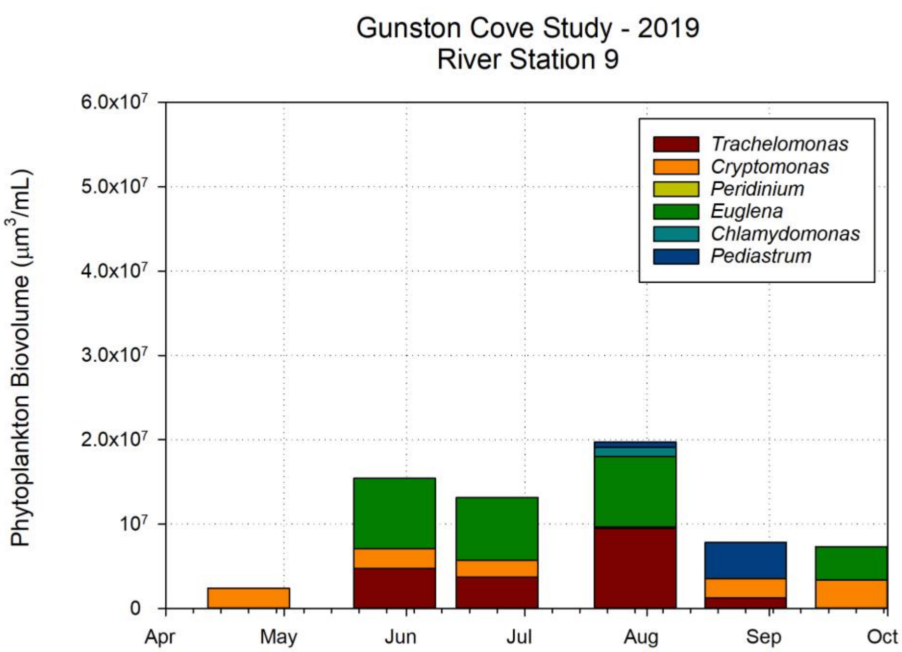


The most numerous phytoplankton among the cryptophytes, green algae and others were:

- *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 2019 including *Euglena*, *Cryptomonas*, and *Trachelomonas* which made strong contributions to biovolume on most dates (Figure 52). In the river the *Euglena* and *Trachelomonas* were most important (Figure 53).

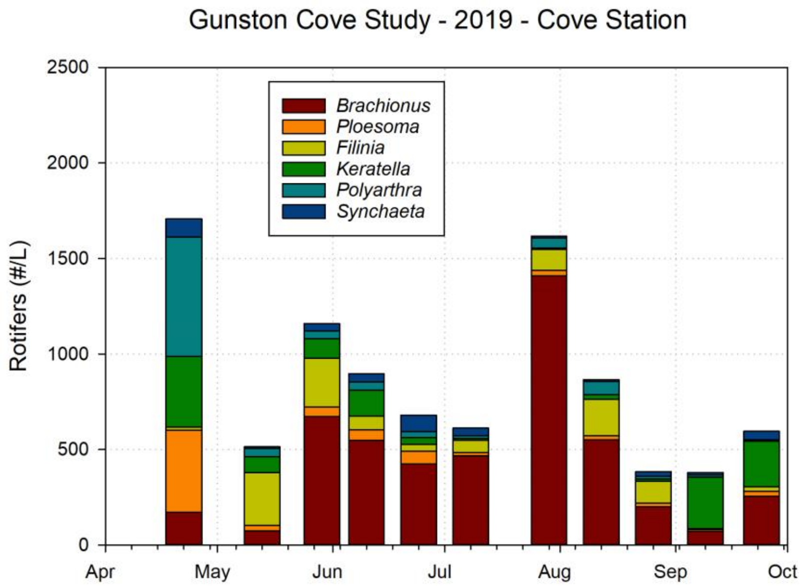


Cryptomonas

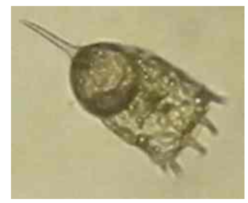
Euglena

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

D. Zooplankton – 2019



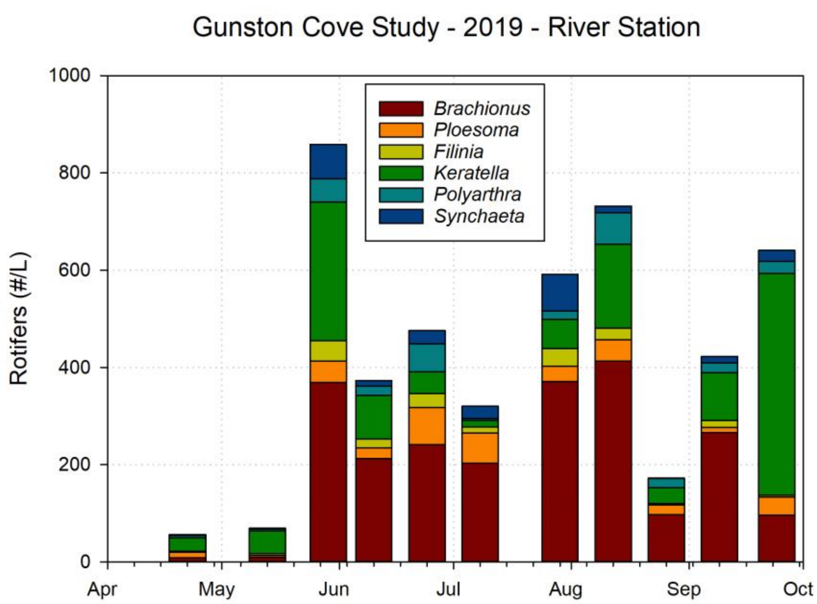
Brachionus (Sta 7, RCJ)



Keratella (Sta 7, RCJ)

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

In the cove, rotifers exhibited a very strong presence in April led by *Polyarthra*. They declined in early June and then increased in late June led by *Brachionus* (Figure 54). A general decline was observed through the summer followed by another peak in late July. *Brachionus* and *Keratella* were most prominent in the fall in the cove. In the river rotifers were consistently less abundant than in the cove, but did have a late May peak led by *Brachionus* and *Keratella*. Levels were fairly stable dominated by *Brachionus* through early August (Figure 55). Densities increased in September, especially due to *Keratella*.



Brachionus (c. 50 um)

Conochilidae

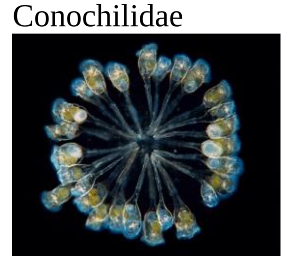
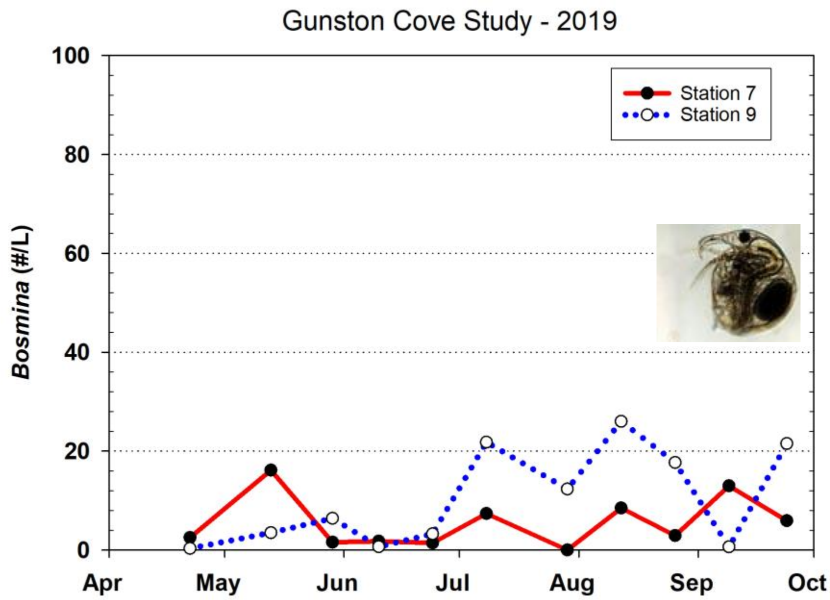


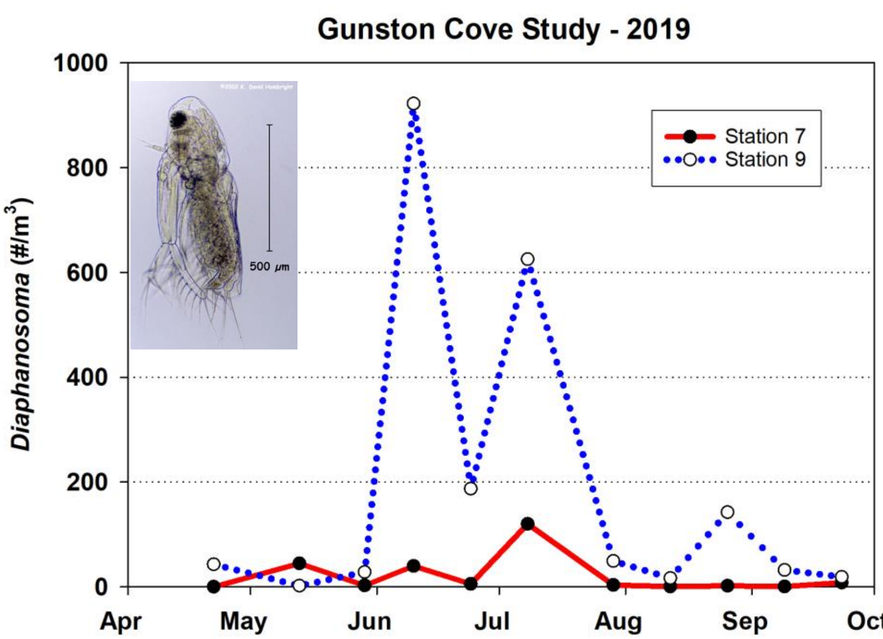
Figure 55. Rotifer Density by Dominant Taxa (#/L). River.



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.

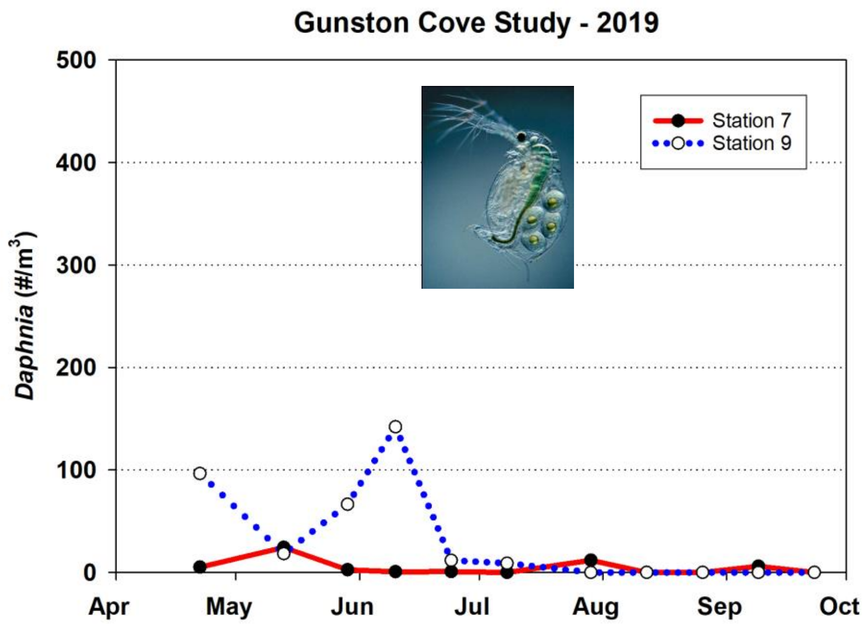
Figure 56. *Bosmina* Density by Station (#/L).

In 2019 the small cladoceran *Bosmina* was present a relatively low levels throughout the year, generally slightly higher in the river (Figure 56). *Diaphanosoma*, typically the most abundant larger cladoceran in the study area, was abundant only in the riever in June at July approaching 1000 per m^3 in early June (Figure 57).



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.

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



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 2019 *Daphnia* exhibited very low values at both stations (Figure 58). *Ceriodaphnia* was observed on only one date (Figure 59).

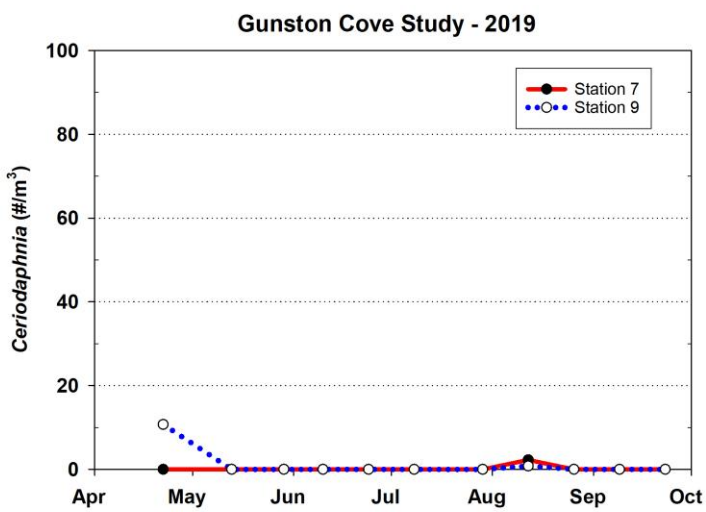
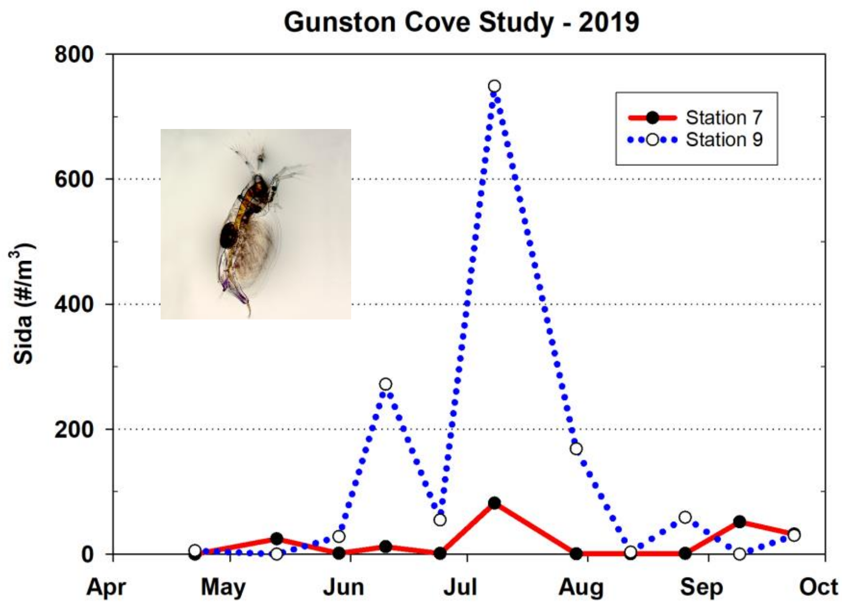


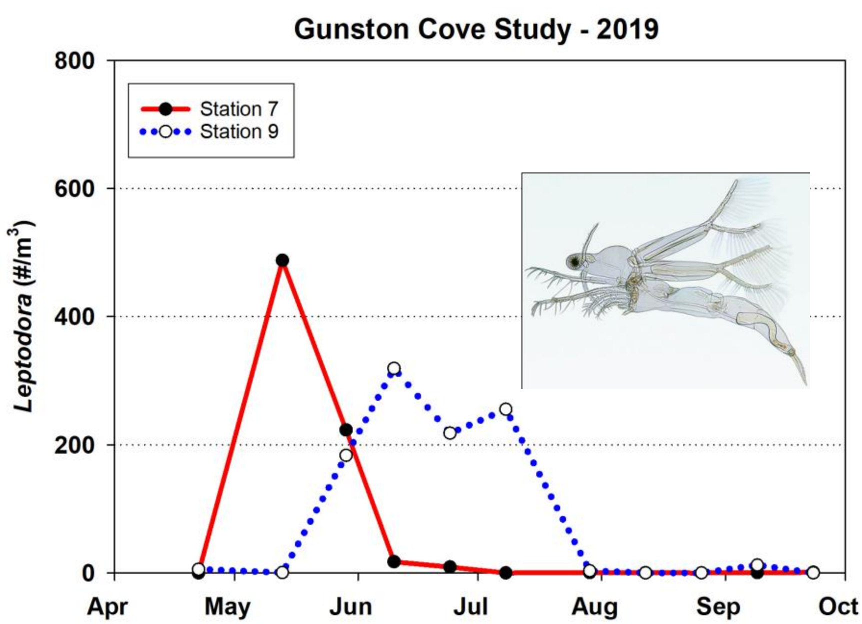
Figure 59. *Ceriodaphnia* Density by Station (#/m^3).



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.

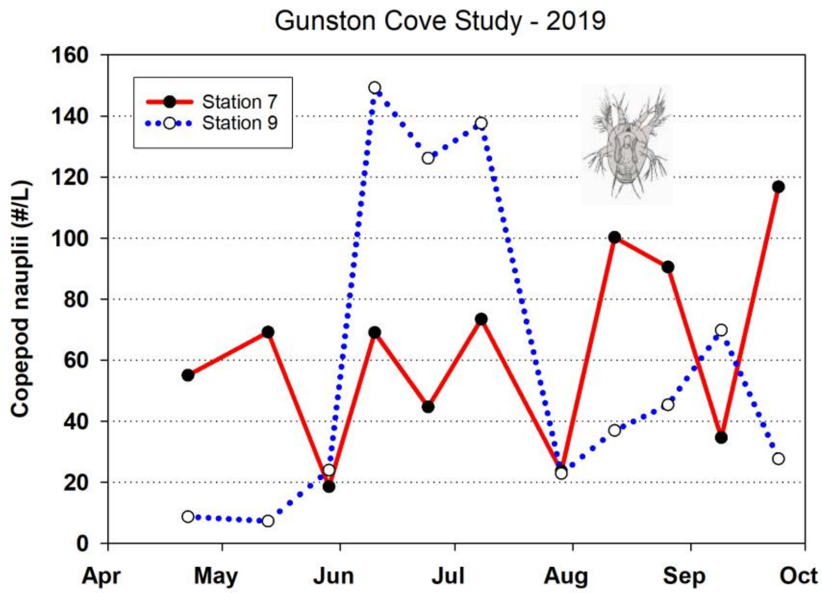
Figure 60. *Sida* Density by Station (#/m^3).

Sida, a smallish cladoceran related to *Diaphanosoma*, was present at relatively high levels in the river approaching 800/m^3 by early July (Figure 60). *Leptodora*, the large cladoceran predator, was quite abundant in 2019 with a peak of nearly 500/m^3 in the cove and 300/m^3 in the river (Figure 61).



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.

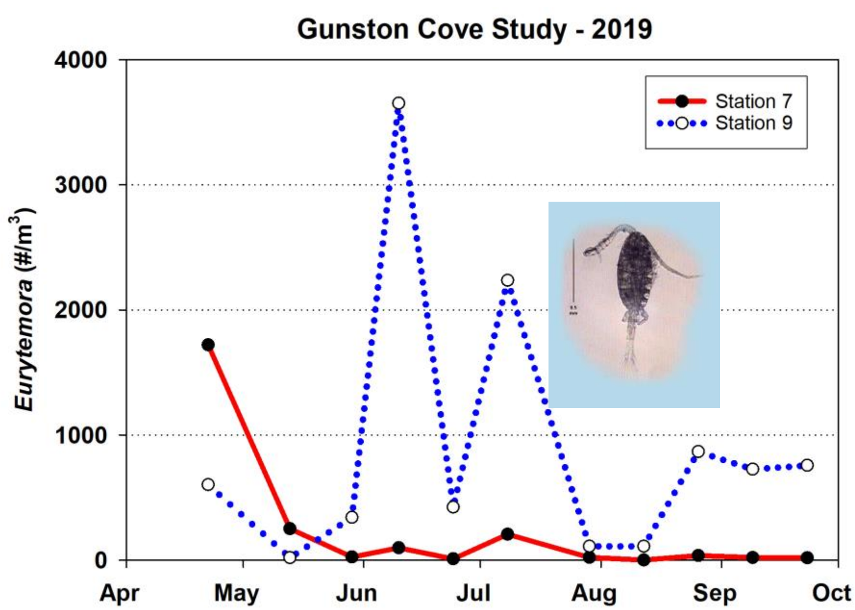
Figure 61. *Leptodora* Density by Station (#/m^3).



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.

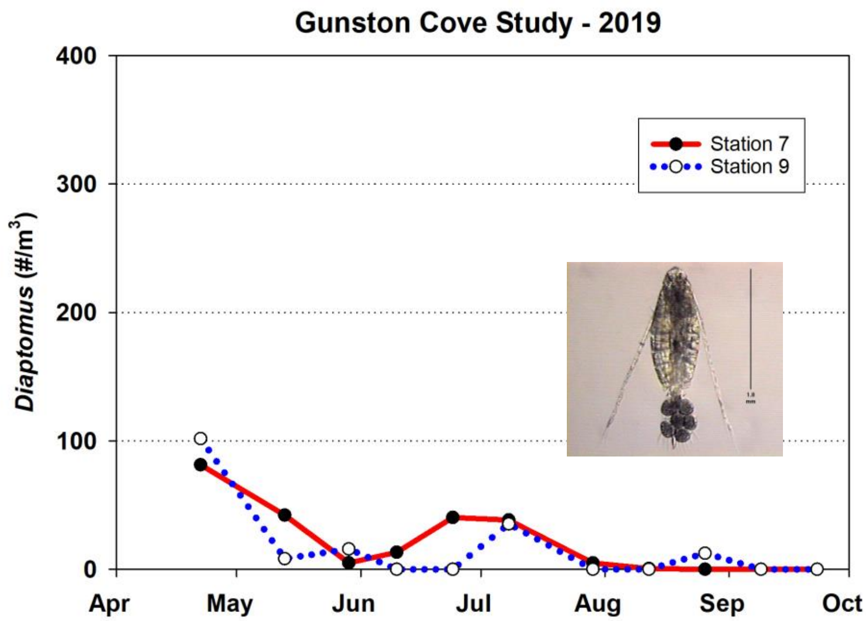
Figure 62. Copepod Nauplii Density by Station (#/L).

In the cove copepod nauplii showed a pattern of gradual increase over the study period punctuated by steep delines in late May, late July, and early September (Figure 62). In the river there was a strong increase in early June through early July. *Eurytemora* attained high densities of nearly 4,000/m^3 in April in the river (Figure 63). In the cove *Eurytemora* had substantial numbers in April, but declined to low values for the rest of the year.



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*.

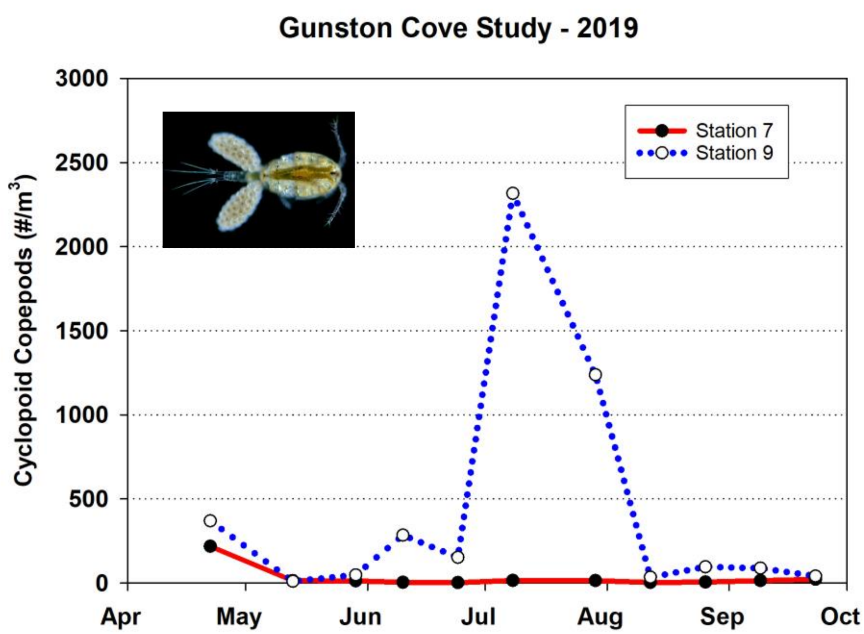
Figure 63. *Eurytemora* Density by Station (#/m^3).



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 in 2019 (Figure 64). Cyclopoid copepods showed a strong peak in the river in July (Figure 65). Cyclopoid copepods were very low in the cove all year.



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-2019

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 2019, we collected 14 samples (7 at Station 7 and 7 at Station 9) during the months April through July and obtained a total of 1399 larvae (Table 4), which is on par with previous years (e.g. 1072 in 2018 and 1751 in 2017). The fish larvae are sometimes too damaged to distinguish at the species level, thus some of the counts are only to the genus level. This year that number was very low; the percent of the catch identified to the Family Clupeidae (but not further) was 5.5% (35.45% last year). Of the Clupeidae that could be identified to the species level, Alewife was the most dominant species with 36.95% of the catch. All clupeids together constituted 93.28% of the catch. Other abundant clupeids were Gizzard Shad at 22.02%, Blueback Herring at 17.73%, Hickory Shad at 9.44% and American Shad at 1.64%. The most dominant non-clupeid species in the catch was White Perch with 3.65% of the catch. Other species somewhat abundant in the ichthyoplankton samples were sunfishes, together at 0.5% of the catch, and Inland Silverside at 0.5%. A total of at least 12 species were identified.

Table 4. The number of larval fishes collected in Gunston Cove and the Potomac River in 2019.

Scientific Name	Common Name	7	9	Total	% of Total
Alosa aestivalis	Blueback Herring	55	193	248	17.73
Alosa mediocris	Hickory Shad	115	17	132	9.44
Alosa pseudoharengus	Alewife	258	259	517	36.95
Alosa sapidissima	American Shad	22	1	23	1.64
Anguilla rostrata	American Eel	1	0	1	0.07
Clupeidae	unk. clupeid species	31	46	77	5.50
Dorosoma cepedianum	Gizzard Shad	53	255	308	22.02
Eggs	Eggs	3	3	6	0.43

Fundulus sp.	unk. killifish species	0	1	1	0.07
Lepomis cyanellus	Green Sunfish	1	0	1	0.07
Lepomis macrochirus	Bluegill	2	0	2	0.14
Lepomis sp.	unk. sunfish	3	1	4	0.29
Menidia beryllina	Inland Silverside	4	3	7	0.50
Morone americana	White Perch	10	41	51	3.65
Strongylura marina	Atlantic Needlefish	1	0	1	0.07
Unidentified	unidentified	11	9	20	1.43
Total		**570**	**829**	**1399**	**100.00**

The mean density of larvae, which takes the volume of water sampled into account over the time sampled, is shown in Figure 56 and 57. Clupeid larvae in Figure 56 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 late May (Figure 66), which is later than last year. The abundance of other larvae than Clupeids was lower, and had peak mid-May (Figure 67). Larval density tends to taper off as the summer progresses, as was seen in 2019. The other larvae included all other taxa listed in Table 4.

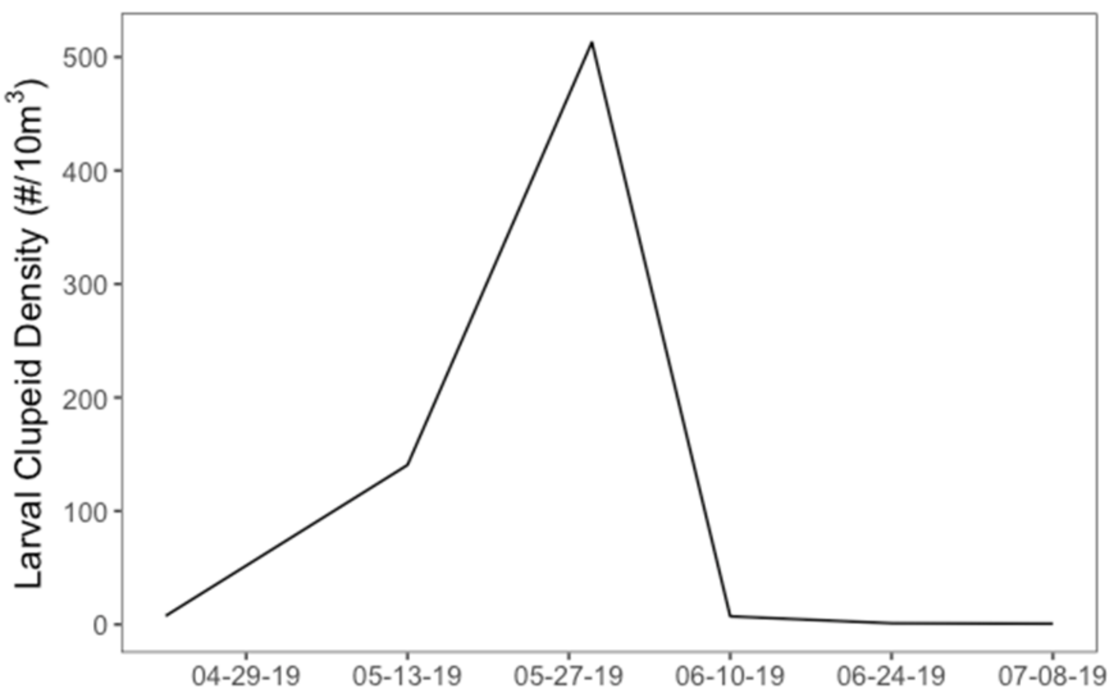


Figure 66. Clupeid larvae, mean density (abundance per $10m^3$).

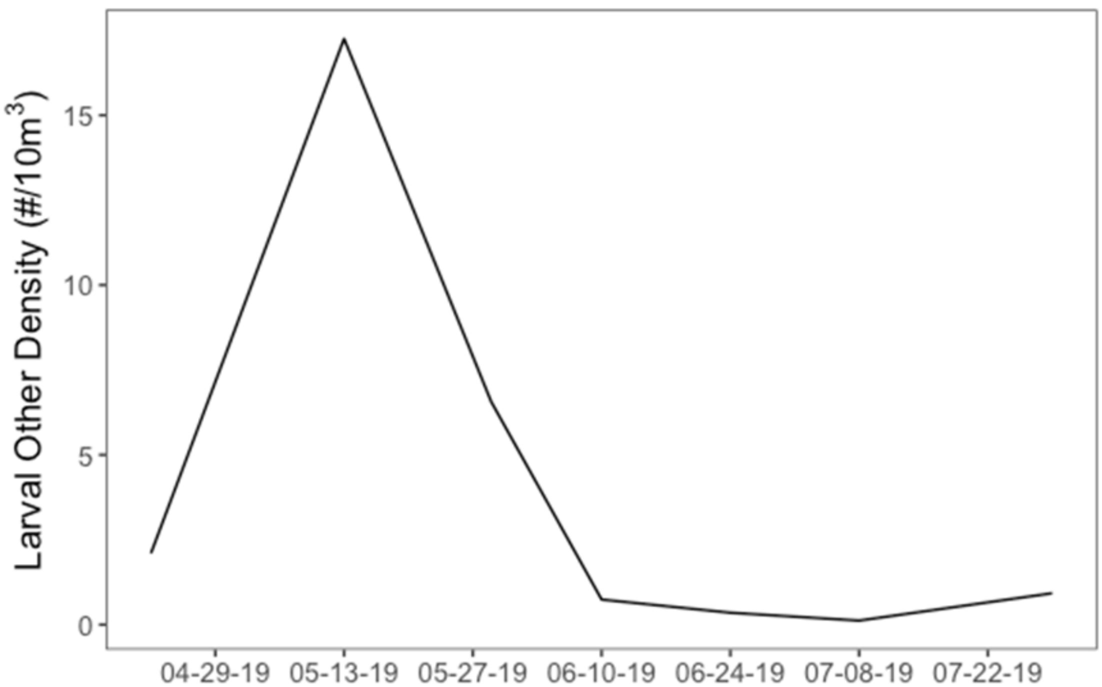


Figure 67. All other larvae, mean density (abundance per $10m^3$)

F. Adult and juvenile fishes – 2019

Trawls

Trawl sampling was conducted between April 26 and September 13 at station 7, 9, and 10. These three fixed stations have been sampled continuously since the inception of the survey. We stopped trawling station 10 in July because extensive SAV growth obstructed the trawl after June. A total of 4315 fishes comprising 24 species were collected in all trawl samples combined (Table 5). This is more than last year, even though we had less trawls due to SAV growth. The most dominant species of the fish collected was White Perch (49.76%, numerically). Dominance of White Perch in the trawls was similar to previous years. Spottail Shiner was the second most abundant species (35.94%); other species had much lower abundances than those two dominant ones, with Eastern Silvery Minnow at 3.24%, Alewife at 2.9%, Blueback Herring at 2.27% and *Alosa sp.* (most likely either Alewife or Blueback Herring) at 1.53%. 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 mid June (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, with numbers remaining high until the end of the sampling season.

Table 5. Adult and Juvenile Fish Collected by Trawling. Gunston Cove Study - 2019.

Scientific Name	Common Name	Abundance	Percent
Morone americana	White Perch	2147	49.76
Notropis hudsonius	Spottail Shiner	1551	35.94
Hybognathus regius	Eastern Silvery Minnow	140	3.24
Alosa pseudoharengus	Alewife	125	2.90
Alosa aestivalis	Blueback Herring	98	2.27
Alosa sp.	unk. Alosa species	66	1.53
Lepomis macrochirus	Bluegill	34	0.79
Etheostoma olmstedi	Tessellated Darter	33	0.76
Lepomis gibbosus	Pumpkinseed	32	0.74
Alosa sapidissima	American Shad	23	0.53
Ictalurus furcatus	Blue Catfish	14	0.32
Anchoa mitchilli	Bay anchovy	12	0.28
Perca flavescens	Yellow Perch	11	0.25
Pomoxis nigromaculatus	Black Crappie	7	0.16
Fundulus diaphanus	Banded Killifish	4	0.09
Alosa mediocris	Hickory Shad	3	0.07
Micropterus salmoides	Largemouth Bass	3	0.07
Ameiurus natalis	Yellow Bullhead	2	0.05
Ameiurus nebulosus	Brown Bullhead	2	0.05
Lepomis auritus	Redbreast Sunfish	2	0.05
Lepomis microlophus	Redear Sunfish	2	0.05
Anguilla rostrata	American Eel	1	0.02
Carassius auratus	Goldfish	1	0.02
Carpiodes cyprinus	Quillback	1	0.02
Menidia beryllina	Inland Silverside	1	0.02
Total		**4315**	**100.00**

Table 6. Adult and Juvenile Fish Collected by Trawling. Gunston Cove Study - 2019.

Scientific Name	Common Name	04-26	05-09	05-20	06-04	06-18	07-02	07-16	08-06	08-21	09-13	Total
Alosa aestivalis	Blueback Herring	0	0	0	0	97	0	0	0	0	1	98
Alosa mediocris	Hickory Shad	0	0	0	0	0	0	0	0	3	0	3
Alosa pseudoharengus	Alewife	0	0	0	0	123	0	0	0	1	1	125
Alosa sapidissima	American Shad	0	0	0	0	23	0	0	0	0	0	23
Alosa sp.	unk. Alosa species	2	0	1	1	23	9	4	0	4	22	66
Ameiurus natalis	Yellow Bullhead	0	0	0	1	1	0	0	0	0	0	2
Ameiurus nebulosus	Brown Bullhead	0	0	0	0	1	0	0	0	1	0	2
Anchoa mitchilli	Bay anchovy	0	0	0	0	0	0	0	7	0	5	12
Anguilla rostrata	American Eel	0	0	0	0	0	1	0	0	0	0	1
Carassius auratus	Goldfish	0	0	0	1	0	0	0	0	0	0	1
Carpiodes cyprinus	Quillback	0	0	0	0	0	0	1	0	0	0	1
Etheostoma olmstedi	Tessellated Darter	3	0	3	5	18	1	0	1	1	1	33
Fundulus diaphanus	Banded Killifish	0	1	0	0	0	0	0	1	2	0	4
Hybognathus regius	Eastern Silvery Minnow	0	0	0	0	0	45	18	37	30	10	140
Ictalurus furcatus	Blue Catfish	0	1	0	3	1	0	4	2	3	0	14
Lepomis auritus	Redbreast Sunfish	0	0	0	0	0	0	0	0	2	0	2
Lepomis gibbosus	Pumpkinseed	1	3	8	4	8	1	0	0	1	6	32
Lepomis macrochirus	Bluegill	8	5	0	1	2	0	2	11	2	3	34
Lepomis microlophus	Redear Sunfish	1	1	0	0	0	0	0	0	0	0	2
Menidia beryllina	Inland Silverside	0	0	0	0	1	0	0	0	0	0	1
Micropterus salmoides	Largemouth Bass	0	1	0	0	1	0	1	0	0	0	3
Morone americana	White Perch	7	1	72	13	907	526	127	239	90	165	2147
Notropis hudsonius	Spottail Shiner	17	5	4	16	358	242	135	181	428	165	1551
Perca flavescens	Yellow Perch	0	0	2	2	6	1	0	0	0	0	11
Pomoxis nigromaculatus	Black Crappie	0	0	0	0	1	1	3	0	1	1	7
Total		**39**	**18**	**90**	**47**	**1571**	**827**	**295**	**479**	**569**	**380**	**4315**

In total numbers and species richness of fish, station 7 dominated the other stations by far with 3206 individuals from 23 species (Table 7, Figure 68a). Stations 9 and 10 had 547 individuals from 11 species and 562 individuals from 19 species respectively (Table 7), which is similar to last year. Station 9 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 at station 9 is Blue Catfish, which is an invasive piscivorous species. One Blue Catfish were collected in the cove as well (station 7). 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 (2017 year was the first year two were found in station 7). A high number of White Perch was collected. While ubiquitous, most by far were collected in the Cove (station 7) in mid-summer (Table 6, Figure 68a and 69a). Spottail Shiner showed a similar pattern and had highest abundance by far with 1277 individuals at station 7 (Table 7, Figure 68a). Highest abundance of Spottail Shiner was at the end of August though (Table 6, Figure 69a). 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 early 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 – 2019.

Scientific Name	**Common Name**	**7**	**9**	**10**
Alosa aestivalis	Blueback Herring	1	96	1
Alosa mediocris	Hickory Shad	3	0	0
Alosa pseudoharengus	Alewife	7	113	5
Alosa sapidissima	American Shad	0	23	0
Alosa sp.	unk. Alosa species	32	13	21
Ameiurus natalis	Yellow Bullhead	2	0	0
Ameiurus nebulosus	Brown Bullhead	2	0	0
Anchoa mitchilli	Bay anchovy	12	0	0
Anguilla rostrata	American Eel	1	0	0
Carassius auratus	Goldfish	1	0	0
Carpiodes cyprinus	Quillback	1	0	0
Etheostoma olmstedi	Tessellated Darter	5	5	23
Fundulus diaphanus	Banded Killifish	3	0	1
Hybognathus regius	Eastern Silvery Minnow	107	33	0
Ictalurus furcatus	Blue Catfish	1	13	0
Lepomis auritus	Redbreast Sunfish	2	0	0
Lepomis gibbosus	Pumpkinseed	15	0	17
Lepomis macrochirus	Bluegill	19	0	15
Lepomis microlophus	Redear Sunfish	0	0	2
Menidia beryllina	Inland Silverside	1	0	0
Micropterus salmoides	Largemouth Bass	2	0	1
Morone americana	White Perch	1699	161	287
Notropis hudsonius	Spottail Shiner	1277	89	185
Perca flavescens	Yellow Perch	6	1	4
Pomoxis nigromaculatus	Black Crappie	7	0	0
Total		**3206**	**547**	**562**

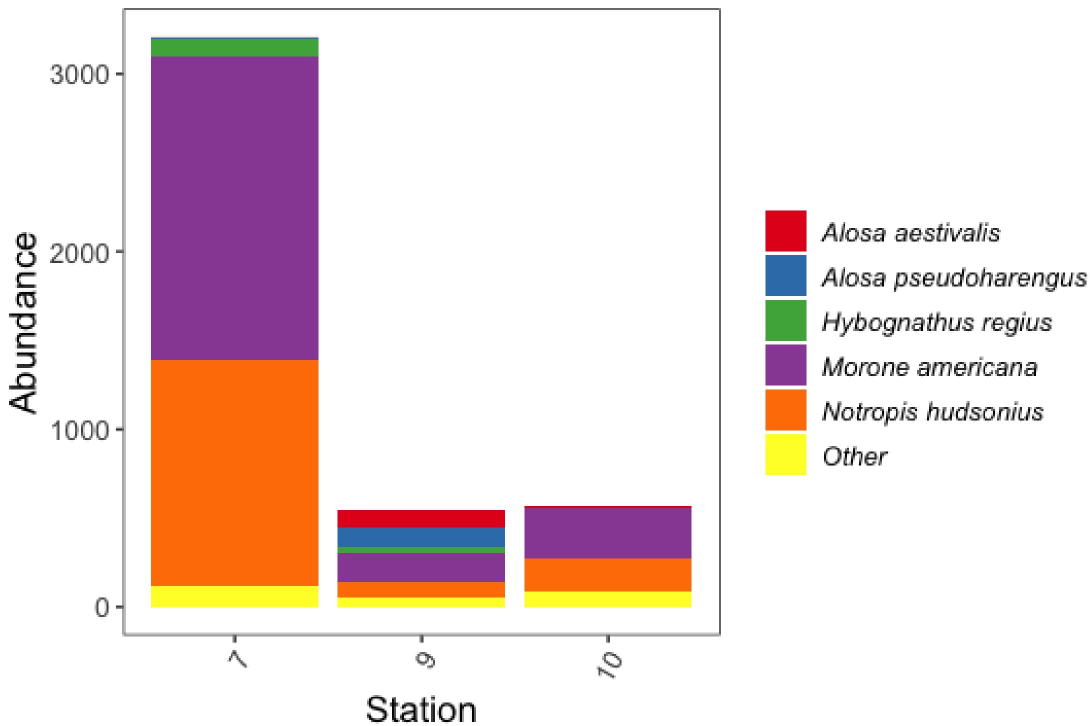


Figure 68a. Adult and Juvenile Fishes Collected by Trawling in 2019. Dominant Species by Station.

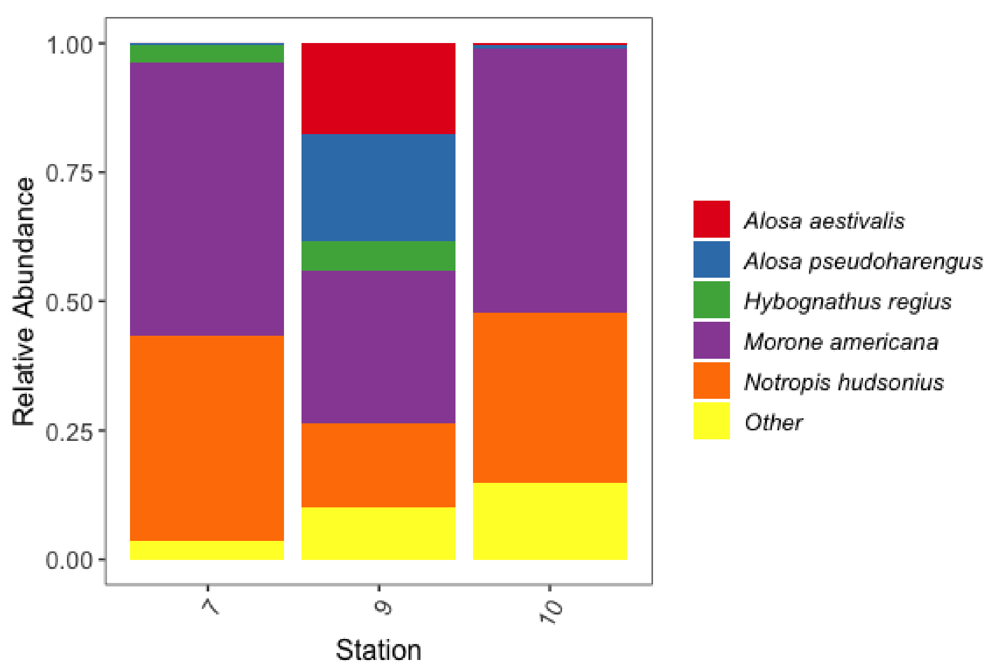


Figure 68b. Relative abundance of Adult and Juvenile Fishes Collected by Trawling in 2019.

The five most abundant species were only present in similar proportions in station 9, at the other two stations (7 and 10) White Perch and Spottail Shiner were so dominant other species hardly made the chart (Figure 68b). At all stations, White Perch made up the most significant proportion of the total catch. Alosines (Alewife and Blueback herring) were only a dominant group in trawl samples at Station 9 this year. Station 7 was overall the most productive site.

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). Spottail Shiner were most abundant in August, with high total abundance in June and July and high relative abundance in April and September as well. The most productive month was June, which in addition to the highest catch of White Perch had the most Alosines as part of the catch as well. Bay Anchovy, a more saline species of which we sometimes encounter a school and collect in relatively high abundance when that happens, was only collected in low abundance at Station 7 this season.

Blueback Herring (*Alosa aestivalis*) and Alewife (*Alosa pseudoharengus*) were formerly major commercial species, but are now depleted 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.

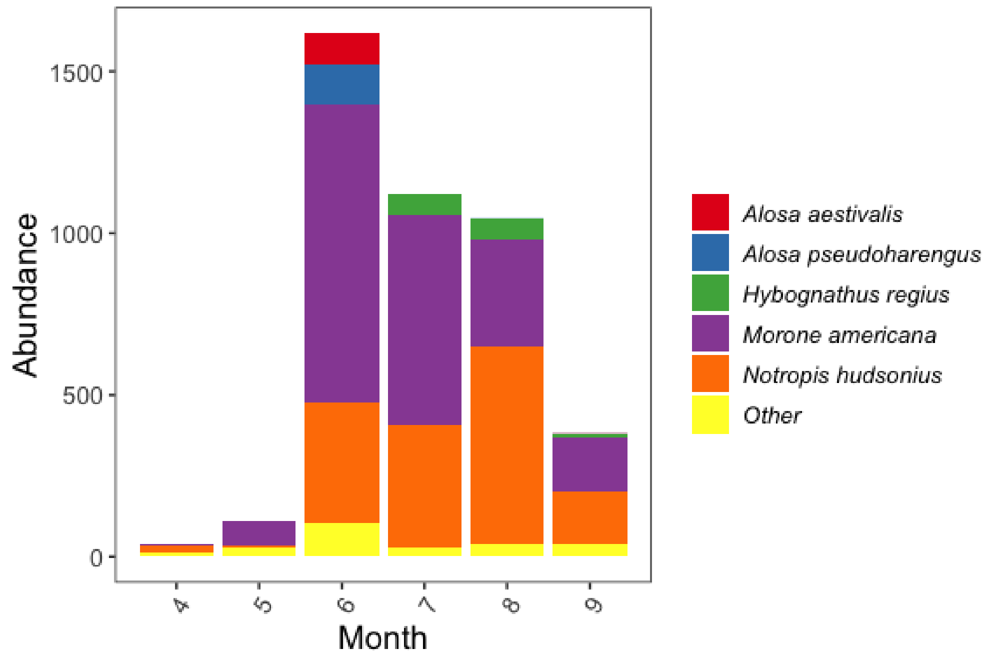


Figure 69a. Adult and Juvenile Fishes Collected by Trawling in 2019. Dominant Species by Month.

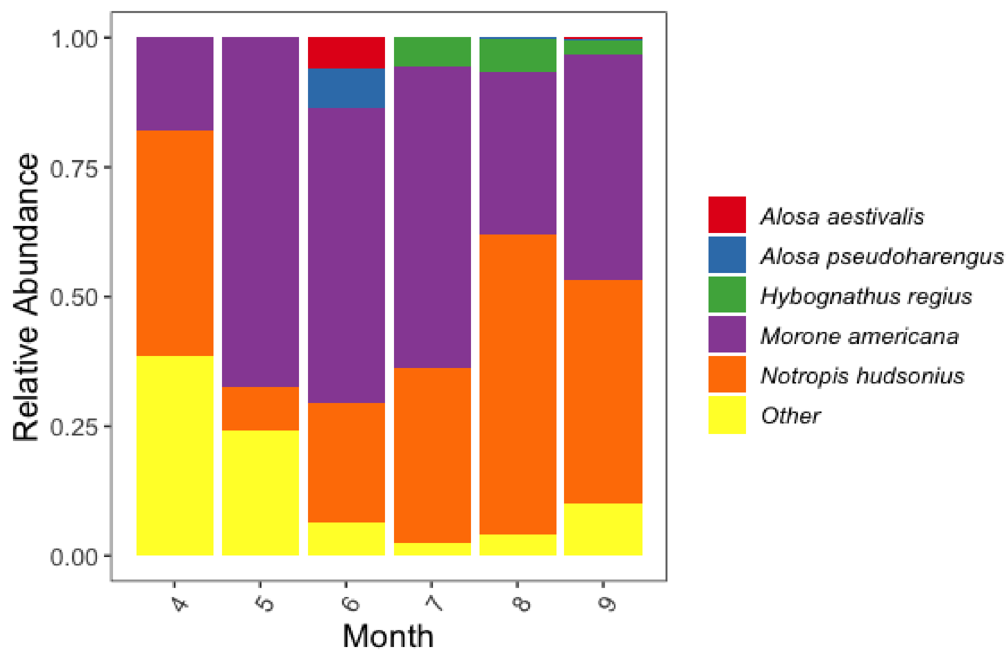


Figure 69b. Relative Abundance for Adult and Juvenile Fishes Collected by Trawling in 2019.

Seines

Seine sampling was conducted approximately semi-monthly at 4 stations between April 26 and September 13. 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 seine 4 until the end of July in 2019, after which SAV obstructed the site.

A total of 37 seine samples were conducted, comprising 4280 fishes of at least 31 species (Table 8). This is 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 37.85%. The second most common species found were *Alosa sp.* (herring or shad) who comprised 24.25% of the catch. White Perch was abundant as well at 13.69% of the catch. Other taxa that contributed at least 1% to total abundance include Inland Silverside (4.35%), Tessellated Darter (3.34%), Eastern Silvery Minnow (3.22%), Quillback (3.18%), Creek Chubsucker (1.73%), Bluegill (1.31%), Mummichog (1.21%), Spottail Shiner (1.14%), and Mosquitofish (1.12%). Other species occurred at low abundances (Table 8).

Banded Killifish was abundant and present at all sampling dates, with higher abundances in May and August (Table 9, Figure 70). The Herring and Shad appeared in high abundance in the catch in May and again in in September. Total catch was not dominated by these two species every sampling date in 2019, with Inland silverside most dominant in April, White Perch most dominant in June, and Tesselated Darter and Eastern Silvery Minnow more abundant than Herring and Shad in June (Table 9, Figure 70).

Herring and Shad were a more dominant group than Banded Killifish in station 11, while Banded Killifish was most dominant at all other Stations (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 highest at Station 11 with 2069 fish and lowest at station 4 with 403 fish (Table 10).

Table 8. Adult and Juvenile Fish Collected by Seining. Gunston Cove Study - 2019.

Scientific Name	**Common Name**	**Abundance**	**Percent**
Fundulus diaphanus	Banded Killifish	1620	37.85
Alosa sp.	unk. Alosa species	1038	24.25
Morone americana	White Perch	586	13.69
Menidia beryllina	Inland Silverside	186	4.35
Etheostoma olmstedi	Tessellated Darter	143	3.34
Hybognathus regius	Eastern Silvery Minnow	138	3.22
Carpiodes cyprinus	Quillback	136	3.18
Erimyzon oblongus	Creek Chubsucker	74	1.73
Lepomis macrochirus	Bluegill	56	1.31
Fundulus heteroclitus	Mummichog	52	1.21
Notropis hudsonius	Spottail Shiner	49	1.14
Gambusia holbrooki	Mosquitofish	48	1.12
Morone saxatilis	Striped Bass	25	0.58
Alosa pseudoharengus	Alewife	21	0.49
Lepomis gibbosus	Pumpkinseed	19	0.44
Carassius auratus	Goldfish	15	0.35
Lepomis microlophus	Redear Sunfish	12	0.28
Alosa mediocris	Hickory Shad	11	0.26
Lepomis auritus	Redbreast Sunfish	9	0.21
Notemigonus crysoleucas	Golden Shiner	9	0.21
Pomoxis nigromaculatus	Black Crappie	9	0.21
Alosa sapidissima	American Shad	5	0.12
Micropterus salmoides	Largemouth Bass	3	0.07
Perca flavescens	Yellow Perch	3	0.07
Semotilus atromaculatus	Creek Chub	3	0.07
Lepisosteus osseus	Longnose Gar	2	0.05
Micropterus dolomieu	Smallmouth Bass	2	0.05
Alosa aestivalis	Blueback Herring	1	0.02
Ameiurus nebulosus	Brown Bullhead	1	0.02
Anguilla rostrata	American Eel	1	0.02
Lepomis sp.	unk. sunfish	1	0.02
Strongylura marina	Atlantic Needlefish	1	0.02
Unidentified	unidentified	1	0.02
Total		**4280**	**100.00**

Table 9. Adult and Juvenile Fish Collected by Seining. Gunston Cove Study - 2019.

Scientific Name	Common Name	4-26	5-09	5-20	6-04	6-18	7-02	7-16	8-06	8-21	9-13	Total
Alosa aestivalis	Blueback Herring	0	0	0	0	0	1	0	0	0	0	1
Alosa mediocris	Hickory Shad	0	5	0	0	0	1	0	0	1	4	11
Alosa pseudoharengus	Alewife	0	4	0	0	3	14	0	0	0	0	21
Alosa sapidissima	American Shad	0	0	0	0	5	0	0	0	0	0	5
Alosa sp.	unk. Alosa species	6	2	354	2	0	21	29	32	1	591	1038
Ameiurus nebulosus	Brown Bullhead	0	0	0	0	0	1	0	0	0	0	1
Anguilla rostrata	American Eel	0	1	0	0	0	0	0	0	0	0	1
Carassius auratus	Goldfish	0	0	0	0	2	3	1	0	2	7	15
Carpiodes cyprinus	Quillback	0	0	0	37	26	70	3	0	0	0	136
Erimyzon oblongus	Creek Chubsucker	0	0	0	0	0	1	4	69	0	0	74
Etheostoma olmstedi	Tessellated Darter	1	4	1	18	24	50	36	4	1	4	143
Fundulus diaphanus	Banded Killifish	35	84	312	134	37	112	96	134	414	262	1620
Fundulus heteroclitus	Mummichog	0	0	0	2	0	11	20	7	9	3	52
Gambusia holbrooki	Mosquitofish	0	2	0	0	0	9	12	6	4	15	48
Hybognathus regius	Eastern Silvery Minnow	0	0	0	0	85	2	0	0	0	51	138
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	3	4	2	9
Lepomis gibbosus	Pumpkinseed	0	1	0	0	3	3	4	0	3	5	19
Lepomis macrochirus	Bluegill	1	0	1	1	3	25	21	0	1	3	56
Lepomis microlophus	Redear Sunfish	0	0	0	0	0	0	0	6	6	0	12
Lepomis sp.	unk. sunfish	0	0	0	0	0	0	0	0	0	1	1
Menidia beryllina	Inland Silverside	64	34	20	8	3	1	4	0	2	50	186
Micropterus dolomieu	Smallmouth Bass	0	0	0	0	0	1	0	1	0	0	2
Micropterus salmoides	Largemouth Bass	1	0	0	0	0	1	1	0	0	0	3
Morone americana	White Perch	17	9	4	0	326	33	50	56	64	27	586
Morone saxatilis	Striped Bass	0	0	0	1	23	1	0	0	0	0	25
Notemigonus crysoleucas	Golden Shiner	4	3	0	1	0	0	0	0	1	0	9

Notropis hudsonius	Spottail Shiner	11	11	0	1	9	9	4	0	3	1	49
Perca flavescens	Yellow Perch	0	1	0	0	1	0	1	0	0	0	3
Pomoxis nigromaculatus	Black Crappie	0	0	0	0	5	3	1	0	0	0	9
Semotilus atromaculatus	Creek Chub	0	0	0	0	0	0	0	0	3	0	3
Strongylura marina	Atlantic Needlefish	0	0	0	0	0	1	0	0	0	0	1
Unidentified	unidentified	0	0	0	0	0	0	1	0	0	0	1
Total		**140**	**161**	**692**	**205**	**555**	**375**	**289**	**318**	**519**	**1026**	**4280**

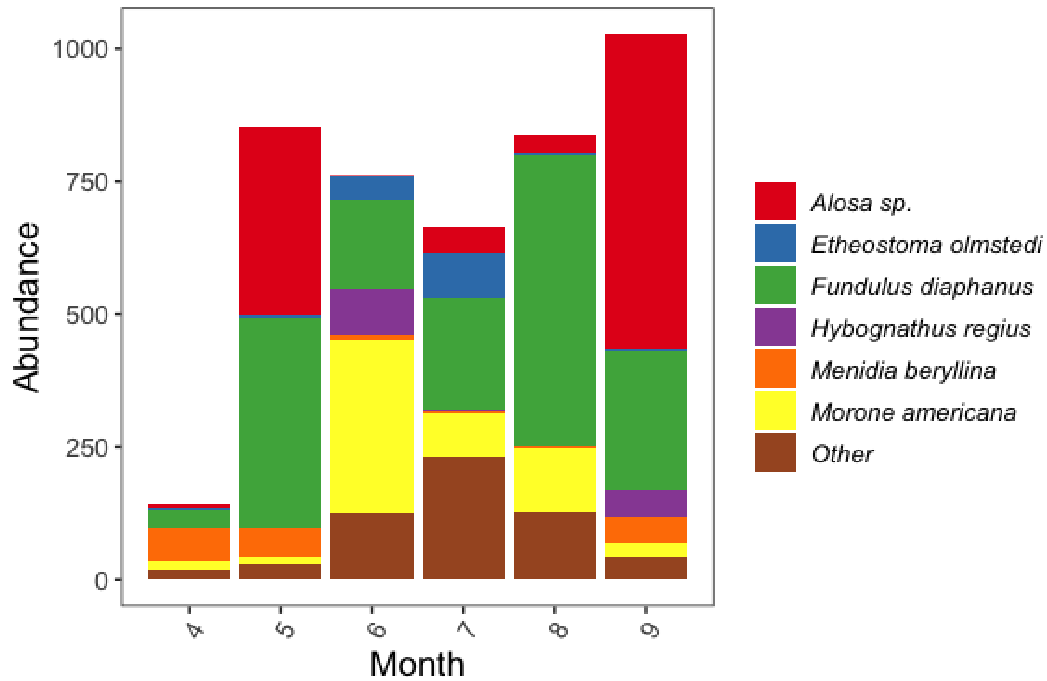


Figure 70. Adult and Juvenile Fish Collected by Seining in 2019. Dominant Species by Month.

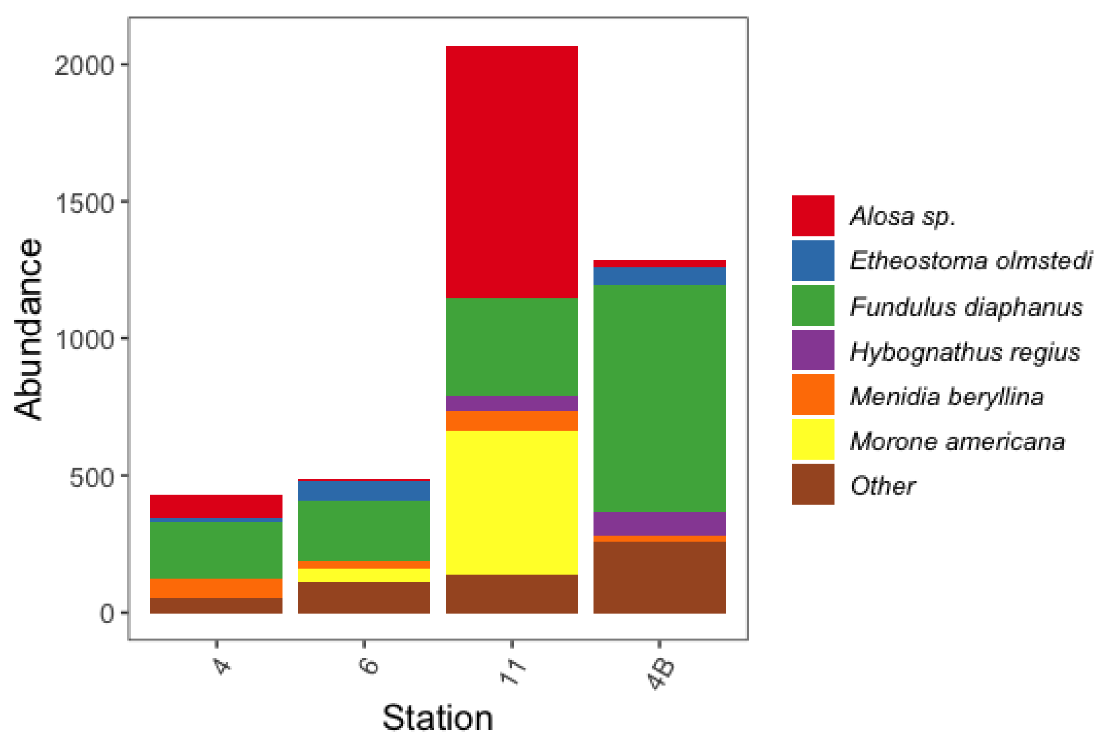


Figure 71. Adult and Juvenile Fishes Collected by Seining in 2019. Dominant Species by Station.

Table 10. Adult and Juvenile Fish Collected by Seining in 2019 per station in Gunston Cove.

Scientific Name	Common Name	4	6	11	4B
Alosa aestivalis	Blueback Herring	0	0	0	1
Alosa mediocris	Hickory Shad	5	0	5	1
Alosa pseudoharengus	Alewife	4	1	15	1
Alosa sapidissima	American Shad	0	0	5	0
Alosa sp.	unk. Alosa species	85	2	922	29
Ameiurus nebulosus	Brown Bullhead	0	1	0	0
Anguilla rostrata	American Eel	0	0	0	0
Carassius auratus	Goldfish	4	7	0	4
Carpiodes cyprinus	Quillback	0	0	50	86
Erimyzon oblongus	Creek Chubsucker	0	1	0	73
Etheostoma olmstedi	Tessellated Darter	12	70	1	60
Fundulus diaphanus	Banded Killifish	206	223	358	833
Fundulus heteroclitus	Mummichog	6	8	0	38
Gambusia holbrooki	Mosquitofish	3	24	0	21
Hybognathus regius	Eastern Silvery Minnow	0	1	53	84
Lepisosteus osseus	Longnose Gar	1	0	0	1
Lepomis auritus	Redbreast Sunfish	0	9	0	0
Lepomis gibbosus	Pumpkinseed	3	6	0	9
Lepomis macrochirus	Bluegill	16	31	1	8
Lepomis microlophus	Redear Sunfish	0	11	0	1
Lepomis sp.	unk. sunfish	0	1	0	0
Menidia beryllina	Inland Silverside	71	24	68	23
Micropterus dolomieu	Smallmouth Bass	1	1	0	0
Micropterus salmoides	Largemouth Bass	1	1	0	1
Morone americana	White Perch	3	50	531	1
Morone saxatilis	Striped Bass	0	0	25	0
Notemigonus crysoleucas	Golden Shiner	1	3	4	1
Notropis hudsonius	Spottail Shiner	1	7	29	4
Perca flavescens	Yellow Perch	0	0	1	1
Pomoxis nigromaculatus	Black Crappie	7	0	0	2
Semotilus atromaculatus	Creek Chub	0	0	0	3
Strongylura marina	Atlantic Needlefish	0	0	1	0
Unidentified	unidentified	0	1	0	0
Total		**430**	**483**	**2069**	**1286**

Fyke nets

We added fyke nets to the sampling regime in 2012 to better represent the fish community present within SAV beds. In 2019 we collected a total number of 870 specimens of at least 15 species in the two fyke nets (Station Fyke 1 and Station Fyke 2; Figure 1b; Table 11), which is more than last year. There was very low SAV cover in 2018, which reduces the efficiency of the fyke nets as they become very visible to the fishes. In 2019 the fyke net catches were comparable to previous years again. The fyke nets show a high contribution of sunfishes (genus *Lepomis*) relative to the other gear types (62.73% of the catch). Other taxa contributing more than 1% of the catch include Banded Killifish at 28.78%, White Perch at 2.73%, Spottail Shiner at 1.46% and Tessellated Darter at 1.38%. We didn't collect native catfishes 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, which was a result of high abundance of all dominant species (Table 12, Figure 72). The SAV cover is highest in August, which serves to hide the nets, generally increasing their catch efficiency. Sunfishes were the dominant species in all months except in July, when Banded Killifish was the most dominant species.

Table 11. Adult and Juvenile Fish Collected by Fyke Nets. Gunston Cove Study - 2019.

Scientific Name	**Common Name**	**Abundance**	**Percent**
Fundulus diaphanus	Banded Killifish	250	28.78
Lepomis macrochirus	Bluegill	229	26.37
Lepomis gibbosus	Pumpkinseed	190	21.85
Lepomis sp.	unk. sunfish	65	7.45
Lepomis microlophus	Redear Sunfish	58	6.73
Morone americana	White Perch	24	2.73
Notropis hudsonius	Spottail Shiner	13	1.46
Etheostoma olmstedi	Tessellated Darter	12	1.38
Carassius auratus	Goldfish	8	0.89
Menidia beryllina	Inland Silverside	7	0.79
Perca flavescens	Yellow Perch	4	0.45
Lepomis auritus	Redbreast Sunfish	3	0.33
Hybognathus regius	Eastern Silvery Minnow	3	0.33
Alosa sapidissima	American Shad	1	0.11
Alosa sp.	unk. Alosa species	1	0.11
Pomoxis nigromaculatus	Black Crappie	1	0.11
Micropterus salmoides	Largemouth Bass	1	0.11
Total		**870**	**100.00**

Table 12. Adult and Juvenile Fish Collected by Fyke Nets. Gunston Cove Study - 2019.

Scientific Name	**Common Name**	**5-09**	**5-20**	**6-04**	**6-18**	**7-02**	**7-16**	**8-06**	**8-21**	**9-13**	**Total**
Alosa sapidissima	American Shad	0	0	0	0	1	0	0	0	0	1
Alosa sp.	unk. Alosa species	0	0	0	0	0	1	0	0	0	1
Carassius auratus	Goldfish	0	0	0	0	1	0	0	1	6	8
Etheostoma olmstedi	Tessellated Darter	0	0	0	0	7	4	1	0	0	12
Fundulus diaphanus	Banded Killifish	0	0	0	0	9	93	42	67	40	250
Hybognathus regius	Eastern Silvery Minnow	0	0	0	0	0	3	0	0	0	3
Lepomis auritus	Redbreast Sunfish	0	0	0	0	0	0	0	1	2	3
Lepomis gibbosus	Pumpkinseed	0	2	0	20	6	7	21	60	75	190
Lepomis macrochirus	Bluegill	0	1	0	0	2	44	66	77	39	229
Lepomis microlophus	Redear Sunfish	0	0	0	0	0	0	1	58	0	58
Lepomis sp.	unk. sunfish	0	0	0	0	0	0	23	32	10	65
Menidia beryllina	Inland Silverside	0	0	3	0	0	2	0	0	2	7
Micropterus salmoides	Largemouth Bass	0	0	0	0	0	0	0	1	0	1
Morone americana	White Perch	0	0	0	1	10	9	1	3	0	24
Notropis hudsonius	Spottail Shiner	0	0	0	0	5	2	3	3	0	13
Perca flavescens	Yellow Perch	0	1	0	0	0	3	0	0	0	4
Pomoxis nigromaculatus	Black Crappie	0	0	0	0	1	0	0	0	0	1
Total		**0**	**4**	**3**	**21**	**42**	**167**	**158**	**302**	**173**	**870**

Fyke 1 had a higher total catch (483 specimens) than Fyke 2 (387 specimens; Table 13, Figure 73). The higher abundance in Fyke 1 was mostly due to the higher abundance of Banded Killifish 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 13. Adult and Juvenile Fish Collected by Fyke Nets. Gunston Cove Study - 2019.

Scientific Name	**Common Name**	**Fyke1**	**Fyke2**
Alosa sapidissima	American Shad	0	1
Alosa sp.	unk. Alosa species	1	0
Carassius auratus	Goldfish	5	3
Etheostoma olmstedi	Tessellated Darter	11	1
Fundulus diaphanus	Banded Killifish	201	49
Hybognathus regius	Eastern Silvery Minnow	0	3
Lepomis auritus	Redbreast Sunfish	2	1
Lepomis gibbosus	Pumpkinseed	92	98
Lepomis macrochirus	Bluegill	98	131
Lepomis microlophus	Redear Sunfish	16	43
Lepomis sp.	unk. sunfish	24	41
Menidia beryllina	Inland Silverside	6	1
Micropterus salmoides	Largemouth Bass	1	0
Morone americana	White Perch	20	4
Notropis hudsonius	Spottail Shiner	5	8
Perca flavescens	Yellow Perch	1	3
Pomoxis nigromaculatus	Black Crappie	1	0
Total		**483**	**387**

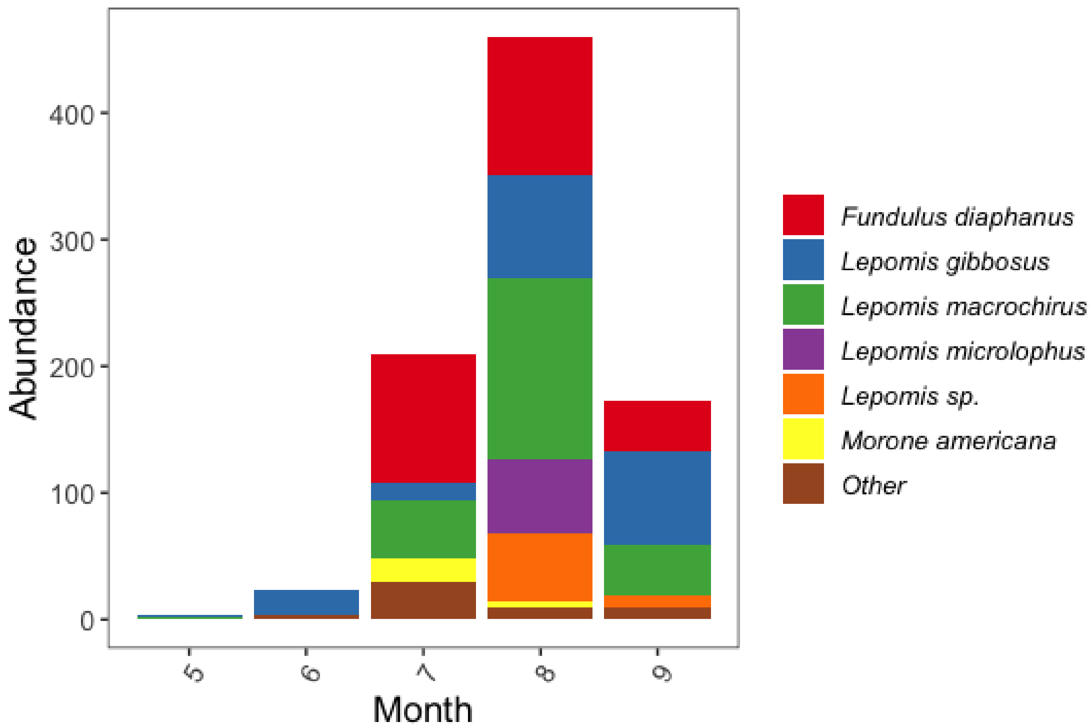


Figure 72. Adult and Juvenile Fish Collected by Fyke Nets. Dominant Species by Month. 2019.

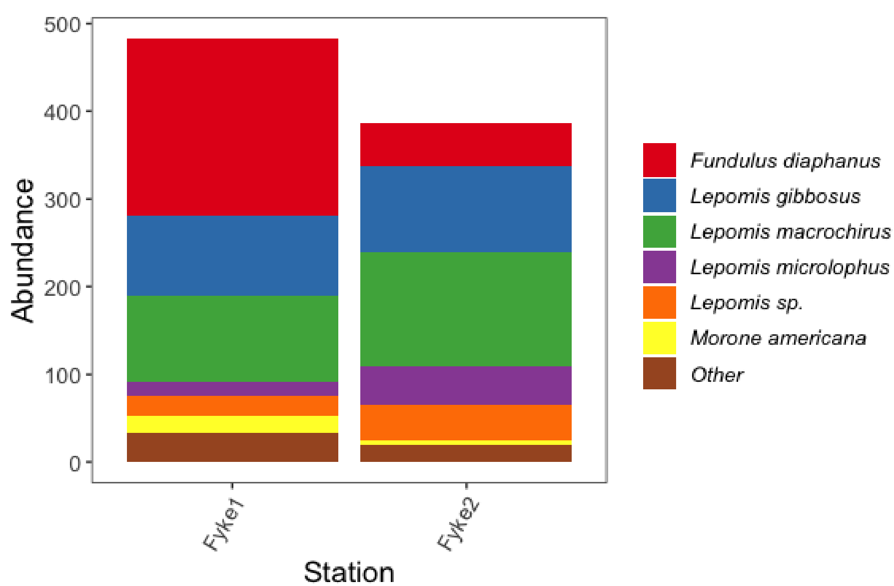


Figure 73. Adult and Juvenile Fishes Collected by Fyke Nets. Dominant Species by Station. 2019.

H. Benthic Macroinvertebrates - 2019

Triplicate petite ponar samples were collected from Gunston Cove proper (Station GC7) and in the Potomac River mainstem (Station GC9) monthly from July through September.

Taxonomic Groups: A total of 7 taxa of benthic macroinvertebrates, belonging to 6 orders and 7 families, were recorded during the survey (Table 14a). One species was non-native (i.e., the Asian clam, *Corbicula fluminea*). Annelid worms, specifically Oligochaetes, were found in high numbers at both sites over all dates. Overall, they accounted for 83% of all benthic organisms found. Insects were the second highest group in abundance across sites and dates, accounting for 13.6% of all individuals accounted for. Chironomids were by far the most numerous and omnipresent insect taxon. The only other insect taxa, the family Hydropsychidae from the order Trichoptera, was only present at GC9 during September. Crustaceans (including amphipods and isopods) were the third highest group in abundance across sites and dates, accounting for 3% of all individuals. Gammarid amphipods (scuds) dominated this group with the isopod *Cyathura polita* being the second most common crustacean (Figure 74). The remainder of the taxonomic groups accounted for minor components of the overall abundance and were found only at GC9. These included Bivalvia (0.2% of total abundance) and Turbellaria (i.e., flatworms) (0.1%). The bivalve group was composed only of the invasive Asian clam, *Corbicula fluminea*.

Table 14a. Taxa Identified in Gunston Cove Tidal Benthic Samples.

Taxon	Common Name	Average # / ponar	
		GC7	GC9
Platyhelminthes	Flatworms	0	1
Annelida-Oligochaeta*	Oligochaete worms	60.67	149.11
Bivalva-Corbicula*	Asiatic clams	0	1.3
Crustacea-Isopoda-Cyathura*	Isopods	0	3.33
Crustacea-Amphipoda-Gammarus*	Amphipods	2	9.33
Insecta-Diptera-Chironomidae*	Midges	31.56	4.17
Insecta-Trichoptera-Hydropsychidae	Caddisflies	0	1
	TOTAL	94.23	169.24

Taxa identified with an asterisk were found on 3 or more station-dates and were included in the multivariate analysis.

Spatial trends: The average abundance of organisms per ponar sample was highest at GC9 in the Potomac mainstem as compared to the site within Gunston Cove (GC7), but this was entirely attributable to the large number of oligochaetes at that station. Both sites were dominated by Annelida, driven by high abundances of Oligochaeta (Figure 74a). GC9 had a higher diversity of taxa (N=7) than GC7 (N=3), likely due to differences in sediment and flow characteristics between the sites. Due to the high abundance of Annelida across all sites, additional analyses were conducted with non-Annelida taxa. Flatworms, bivalves, isopod crustaceans, and Hydropsychidae insects were present only at GC9. However, Chironomid insect larvae were more numerous at GC7 than GC9. When examining all non-Annelida taxa, Insects were the dominant group in percent contribution at GC7 (94%), while Crustaceans dominated at GC9 (59%)

(Figure 74c). Other taxa varied in their percent contribution by site. For example, Bivalvia and Turbellaria were only found at GC9.

Temporal trends: Annelida, composed of only oligochaetes, were the dominant taxa recorded during all months (Figure 74b). There was a seasonal decline in crustaceans driven by Gammarid amphipods, which peaked during July most likely due to recruitment and were relatively low during the later months. Average bivalvie abundances were relatively constant across the sampling period (average of 1-2 individuals/ponar) but only at GC9 and were driven by abundances of the invasive Asian clam *Corbicula fluminea*. Average abundances of Turbellaria were highest during July at GC9. The lowest average Comparing percent contributions of all non-Annelida taxa across all of the sites, months were dominated by Insecta (July – 59%, August – 77%, September – 88%) (Figure 74d). Overall, larger increases in abundances and relative percent contributions over the sampling period for many of the taxa described above are in direct relation to seasonal changes and recruitment.

Influence of Habitat on Community Composition: For this analysis, only communities collected in July, 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 14b). At GC9 the macroinvertebrate abundance was 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 xx). 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 – 93.9% shell and 6 – 100% leaves or woody debris). There was only one sampling date and site in which SAV was recovered – September at GC7.

Table 14b. Large substrate composition vs. total abundance of benthic macroinvertebrates in individual replicate samples.

	%Leaves/Wood	%Shell	%SAV	Total Abundance
GC7July1	100.0	0.0	0.0	17
GC7July2	23.4	76.6	0.0	109
GC7July3	50.7	49.3	0.0	90
GC7Aug1	35.2	64.8	0.0	68
GC7Aug2	77.4	22.6	0.0	59
GC7Aug3	89.6	10.4	0.0	118
GC7Sept1	98.6	0.0	1.4	89
GC7Sept2	6.0	93.9	0.1	191
GC7Sept3	83.6	16.4	0.0	93
GC9July1	3.7	96.3	0.0	153
GC9July2	1.6	98.4	0.0	155
GC9July3	1.5	98.5	0.0	253
GC9Aug1	9.4	90.6	0.0	187
GC9Aug2	7.2	92.8	0.0	117
GC9Aug3	9.6	90.4	0.0	118
GC9Sept1	20.7	79.3	0.0	131
GC9Sept2	5.0	95.0	0.0	147
GC9Sept3	6.5	93.5	0.0	179

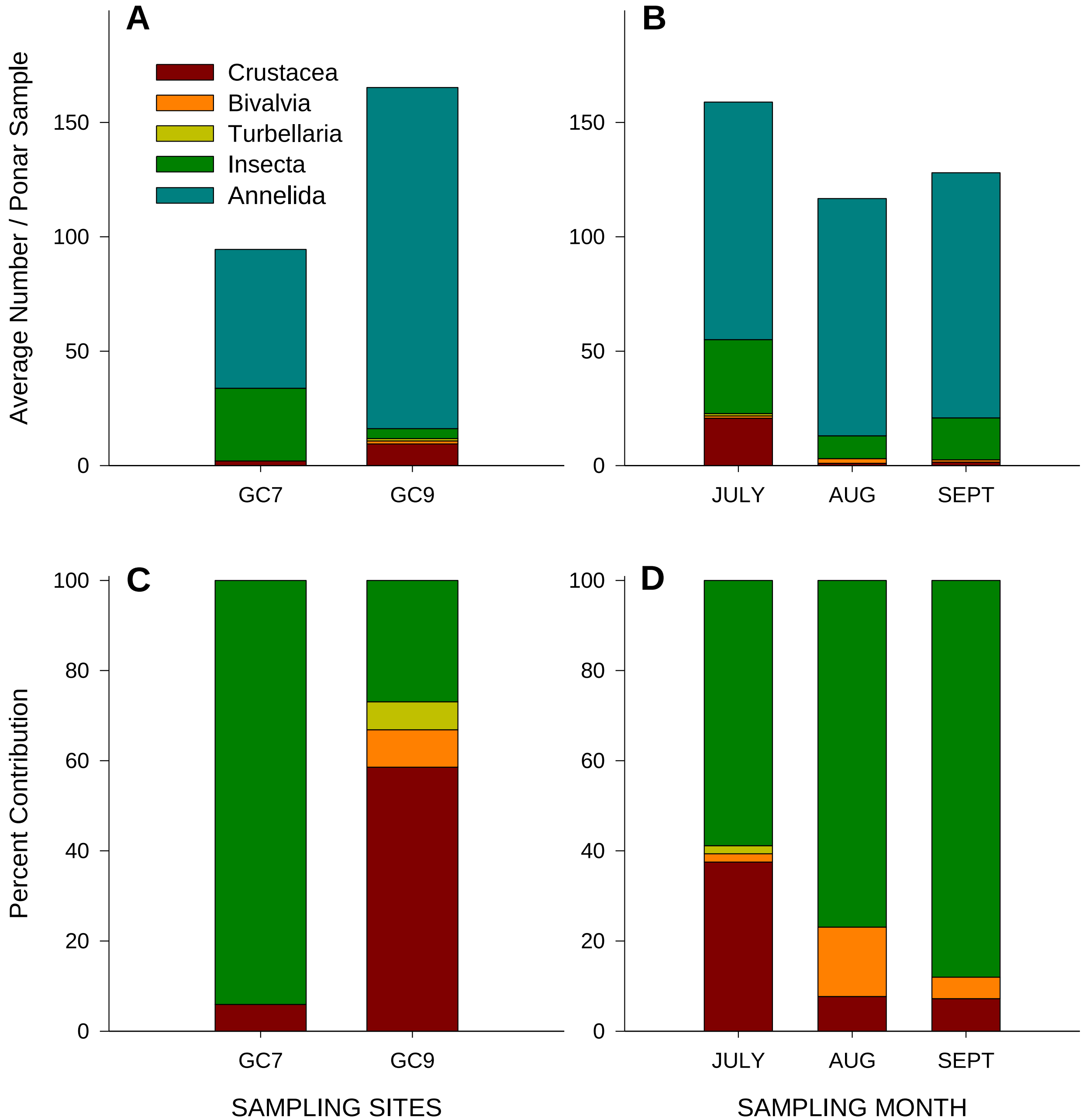


Figure 74. Average number per ponar sample of all benthic macroinvertebrate taxa (A, B) and percent contribution of all non-Annelida benthic macroinvertebrate (C, D) in petite ponar samples collected in 2019 separated by site and month.

Multivariate analyses: Due to the multispecies aspect of benthic communities, it is often useful to use multivariate analyses or ordination to examine relationships among samples. This allows multiple taxa to be considered simultaneously when assessing these relationships. In order to get the most meaningful relationships, the full macroinvertebrate sample/taxa matrix was condensed. Taxa that were present in less than three of the original replicate sample matrix were excluded. Then, the remaining, more consistently found taxa were used in the analysis (indicated by asterisks in Table 14a) were averaged over the replicates for each date and station combination. This resulted in one set of taxa values for each station on each date.

This reduced matrix (6 samples x 5 taxa) was then subjected to an ordination using a technique called Non-metric Multidimensional Scaling (nMDS). This allows relationships among samples based on their full complement of taxa to be visualized. If successful, relationships among samples can be shown on a two dimensional plot. The taxa differences responsible for the observed relationships can also be examined. The program PRIMER v.6 was used to conduct the ordinations.

The results of an nMDS ordination using presence-absence data is shown in Figure 75. All of the GC7 samples separate from the GC9 samples, as noted by the two circles of data points. The GC7 samples had either 2 or 3 taxa as compared to either 4 or 5 taxa apparent in GC9 samples. The September GC7 samples were different from the other months because this was the only month in which Gammarid crustaceans were found in the samples. The higher richness at GC9 is probably due to better habitat conditions especially large and more heterogeneous sediment particle size.

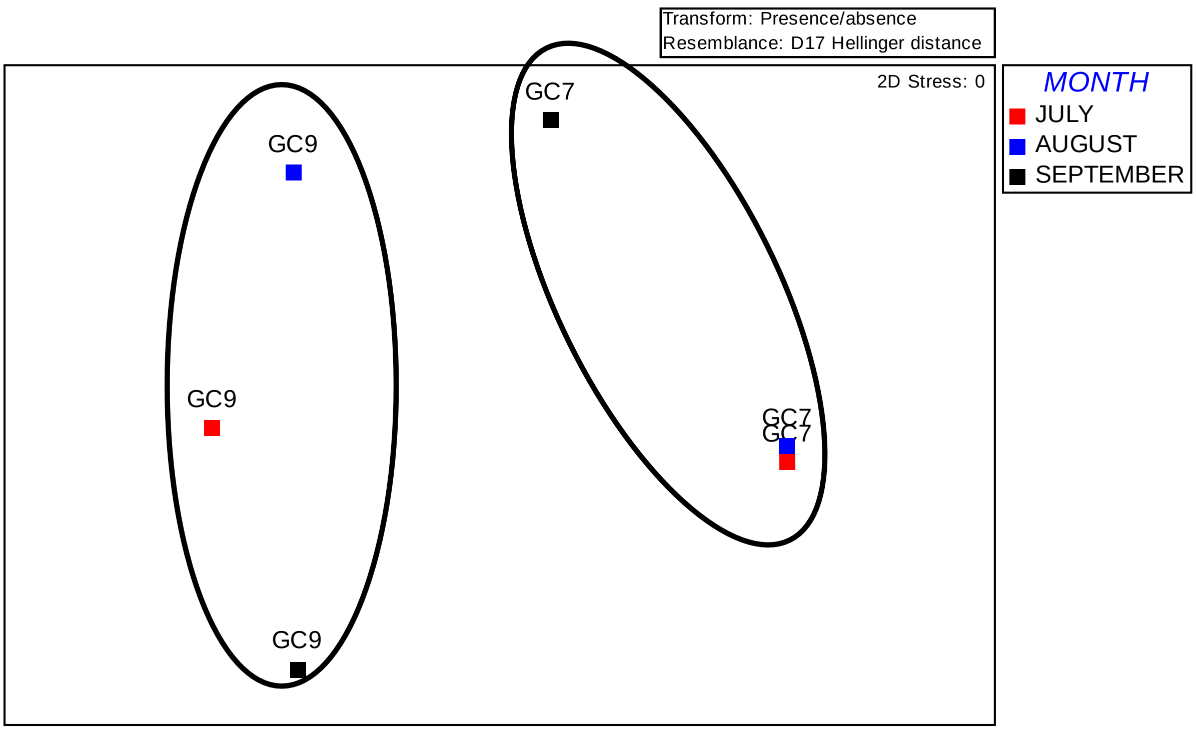


Figure 75. nMDS ordination of benthic samples from tidal stations. The station names are placed above each symbol. Colors represent month. Triplicates were averaged to get a single value for each month-station combination. Data was presence/absence and distance measure was Hellinger.

H. Submersed Aquatic Vegetation – 2019

The Virginia Institute of Marine Science annual aerial SAV survey was resumed in 2019. Results indicate a return to aerial coverage over most of the inner Cove area similar to that observed in most years since 2005 (Figure 76).

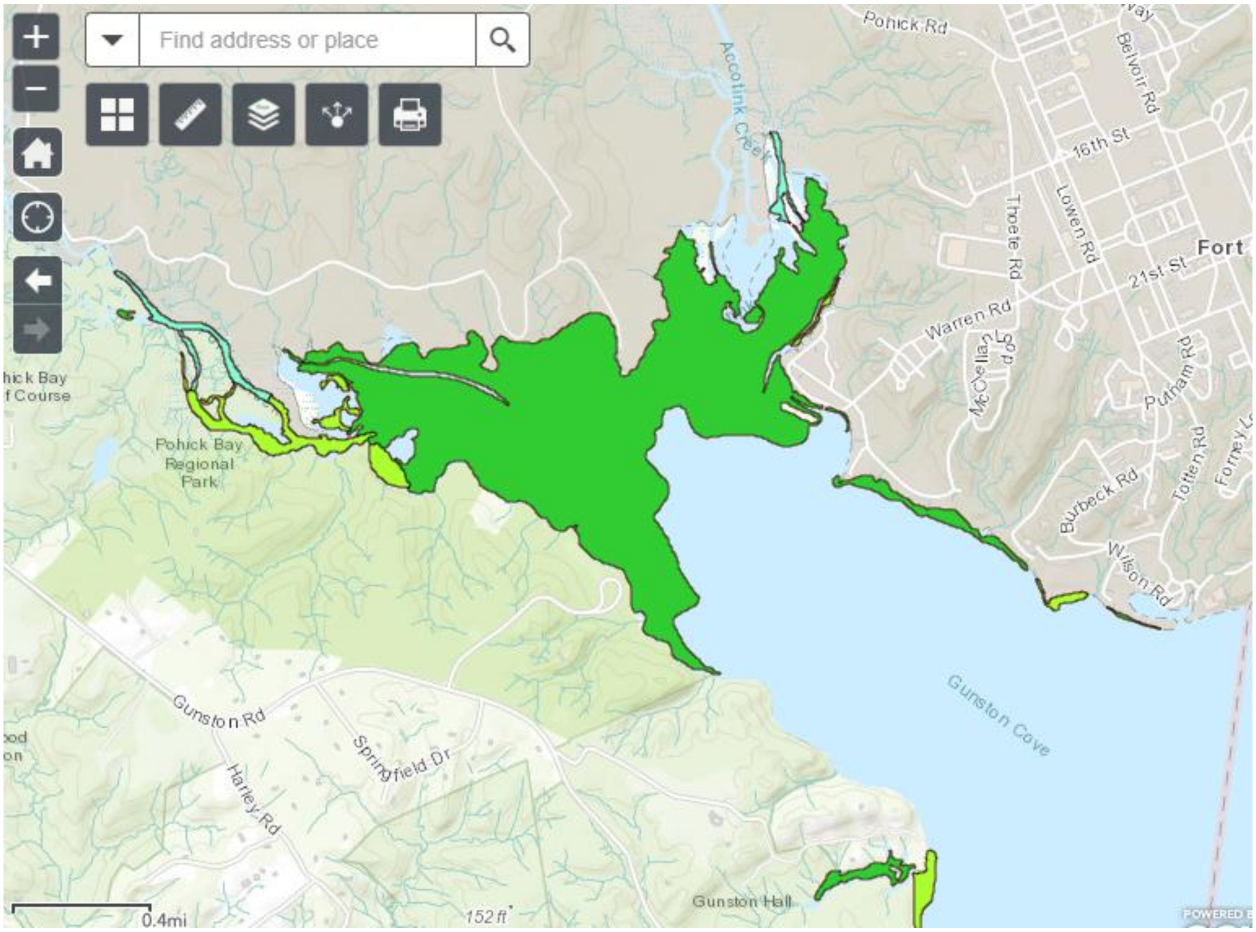


Figure 76. Coverage of Submersed Aquatic Vegetation in Gunston Cove. VIMS SAV program. Interactive SAV map for 2019. Accessed May 18, 2020.
https://www.vims.edu/research/units/programs/sav1/access/maps/index.php

The distribution of dominant SAV taxa was determined at 31 points in the inner portion of Gunston Cove during the datamapping cruise by inserting a garden rake to the bottom, twisting it to collect plants and pulling it on board. The results are summarized in Table 15. *Hydrilla verticillata* was found at about half of the sites, but its coverage intensity was generally only moderate. *Najas minor* and *Zosterella dubia* were present at about ¼ of points at moderate density at each site. *Vallisneria americana* and *Certatophyllum demersum* were present at a few scattered locations. These results demonstrate that SAV made a partial recovery in 2019 from the very low coverage and density observed in 2018. Note that some of the datamapping cruise occurred outside of the area of SAV coverage (Figure 6).

Table 15. Relative abundance of dominant SAV species determined during data mapping cruise.

Scientific Name	Common Name	Freq (#)	Freq (%)	Avg. Density
Hydrilla verticillata	hydrilla	18	58.1	2.03
Ceratophyllum demersum	coontail	2	6.4	0.75

Najas minor	minor naiad	9	29.0	1.44
Vallisneria americana	water celery	3	9.7	0.67
Zosterella dubia	water stargrass	7	22.6	2.93

A total of 31 points were sampled for SAV with a water depth of 2.1 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 4 (very abundant).

DISCUSSION

A. 2019 Data

In 2019 air temperature was above average from April through September. Precipitation was above normal from May through July, but below normal in August and September. Rainfall and runoff patterns relative to sampling dates are shown in Figure 77. The water quality sample dates that were preceeded by substantial rainfall were May 13 and, especially, July 8. On July 6, 1.7 cm of rain fell and then on July 8 there was 8.7 cm of rain. River flows which could impact the study area followed the typical seasonal pattern. In March and April flows were near normal, but in May and again in July, they were substantially elevated (see Figure 2).

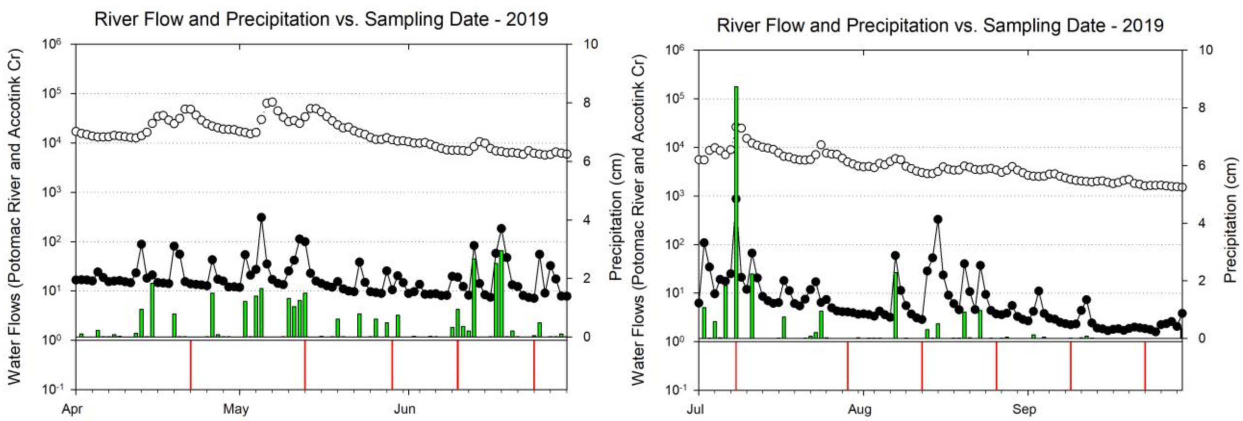


Figure 77. Precipitation (green bars), Accotink Creek flows (solid circles), Potomac River flows (open circles) and water quality/plankton sampling events (red lines at bottom).

Mean water temperature was similar at the two stations with a pronounced dip in early June and a peak of about 30° in July. Specific conductance exhibited a gradual rise throughout the study period at both stations and showed little response flow events. Dissolved oxygen saturation and concentration (DO) were more variable in the cove and there was little seasonal pattern at either site. Field pH patterns mirrored those in DO. Total alkalinity was generally higher in the river than in the cove. In the cove the two major dips in total alkalinity corresponded to the two dates preceded by substantial rainfall. Water clarity as measured by Secchi disk transparency and light attenuation coefficient quite similar at the two station for most of the year although more variability was exhibited in the Cove. In the cove water clarity dropped on one of the high rainfall dates, July 8, and increased dramatically in September.

Ammonia nitrogen was consistently low in the study area during 2019, but almost all values were below the limits of detection making analysis of any temporal or spatial trends impossible. Nitrate values declined steadily through the entire study period at both stations with river values consistently about 0.5 mg/L than those in the cove. Nitrite was much lower overall. Organic nitrogen showed a general seasonal decline punctuated by a major dip in late May. Total phosphorus showed a major peak corresponding to the early July runoff event. Soluble reactive phosphorus was generally somewhat higher in the river, but showed little seasonal trend. N to P ratio did not show a consistent seasonal pattern, but was generally in the 12-40 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 July runoff event. 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 through most of the year. High values in the cove in April were strongly decreased in early May, a possible flow impact. A steady increase followed through early July and then a decline through the remainder of the year. The April maximum was composed predominantly of diatoms with *Melosira* being the most important. In the river phytoplankton chlorophyll was generally lower than in the cove and pennate diatoms were dominant in April while euglenoids were most important in May and June.

Rotifers continued to be the most numerous microzooplankton in 2019. Rotifer densities were unusually high in April in the cove with mixed taxa dominance. A decline in early May in the wake of the flow event was following by generally higher bu declining values until a peak in lat July. In June *Brachionus* became the dominant rotifer for the remainder of the year at both stations. Rotifer densities were consistently lower in the river than in the cove with peaks in late May and early August. *Bosmina*, a small cladoceran was low at both stations in 2019. *Diaphanosoma*, a larger cladoceran, was much more common in the river with marked peaks in early June and early July. *Daphnia* was only found at low values in 2019. *Sida* was present in the river at the same times as *Diaphanosoma*. *Leptodora* exhibited a peak in early May in the cove and early June in the river. Copepod nauplii were found in variable numbers in the cove and had a distince seasonal pattern in the river with highest values from June through early July. The calanoid copepod *Eurytemora* was very abundant in the cove in April but was much lower for the rest of ther year. It showed strong peaks in early June and early July in the river. A second calanoid *Diaptomus* was found at much lower levels, mainly in April in the cove. Cyclopoid copepods had a strong maximum in the river in July, but otherwise were at low levels.

In 2019 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 late May, which was driven by a high density of Clupeid larvae. The non-clupeid larval density was highest in mid-May, which was driven by White Perch larvae.

Submerged aquatic vegetation returned in 2019 after 2018's very low cover, which resulted in fish abundances and gear efficiency that was similar to the years before 2018. In trawls White Perch dominated, followed by Spottail Shiner. White Perch was by far the most abundant species and was found in all months at all stations, with peak abundance in June. We collected a lot less Blue Catfish than last year, but still 13 in the mainstem and 1 in the cove. Abundances have likely not reduced since last year, large specimens tend to avoid our gear. Last year more than a hundred invasive Blue Catfishes were collected with the trawl, of which only one in the cove and the rest in the mainstem. With the smaller catch in 2019, we still found a 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 four native catfishes in the cove and none in the mainstem.

In seines, the most abundant species was Banded Killifish. 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 August. Other taxa with high abundances were Herring and Shad, with a similar abundance pattern as Banded Killifish. Numerous small Alosa juveniles started appearing in the samples in late May, 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, Inland Silverside, Tessellated Darter and Eastern Silvery Minnow.

Fyke nets were part of the sampling regime again in 2019. The total catch of the fyke nets is smaller than the other gears, and was similar again to previous years after low SAV cover rendered the 2018 Fyke net catch very small. Fyke nets represent 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 in addition to Banded Killifish, which are underrepresented in the seine and trawl catches since they tend to stay within the SAV. Sunfishes that could be identified to the species level were represented in order of abundance by Bluegill, Pumpkinseed, and Redear Sunfish. Highest abundance of all species collected with fyke nets occurred in August, when SAV cover is most extensive.

As in most previous years, oligochaetes were the most common invertebrates collected in ponar samples in 2019. Chironomids (midge larvae) were second most dominant in the cove. Amphipods, isopods, and chironomids were common in the river. Multivariate analysis showed a clear and consistent difference between cove benthic communities and those in the river. Shells were the most dominant large substrate in river benthic samples. In the cove both shells and plant detritus were abundant.

Coverage of submersed aquatic vegetation (SAV) in 2019 rebounded very strongly after very limited abundances due to high turbidity and subsequent low light levels. *Hydrilla*, minor naiad, and water stargrass were the most abundant SAV.

B. Water Quality Trends: 1983-2019

To assess long-term trends in water quality, data from 1983 to 2019 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 16 and 17). This was similar to the analysis performed in previous reports.

Table 16
Correlation and Linear Regression Coefficients
Water Quality Parameter vs. Year for 1984-2019
GMU Water Quality Data
June-September

	Station 7			Station 9		
Parameter	Corr. Coeff.	Reg. Coeff.	Signif.	Corr. Coeff.	Reg. Coeff.	Signif.
Temperature	0.189	0.050	0.001	0.094	-----	NS
Conductivity, standardized to 25°C	0.137	1.53	0.015	0.005	-----	NS
Dissolved oxygen, mg/L	0.070	-----	NS	0.194	0.022	0.001
Dissolved oxygen, percent saturation	0.008	-----	NS	0.221	0.320	<0.001
Secchi disk depth	0.699	1.71	<0.001	0.309	0.468	<0.001
Light attenuation coefficient	0.674	0.085	<0.001	0.092	-----	NS
pH, Field	0.202	-0.012	0.001	0.198	0.008	0.002
Chlorophyll, depth-integrated	0.629	-3.67	<0.001	0.320	-0.786	<0.001
Chlorophyll, surface	0.615	-3.70	<0.001	0.301	-0.860	<0.001

For Station 7, n=312-331 except pH, Field where n=265 and Light attenuation coefficient where n=249.
For Station 9, n=270-284 except pH, Field where n=232 and Light attenuation coefficient where n=219.

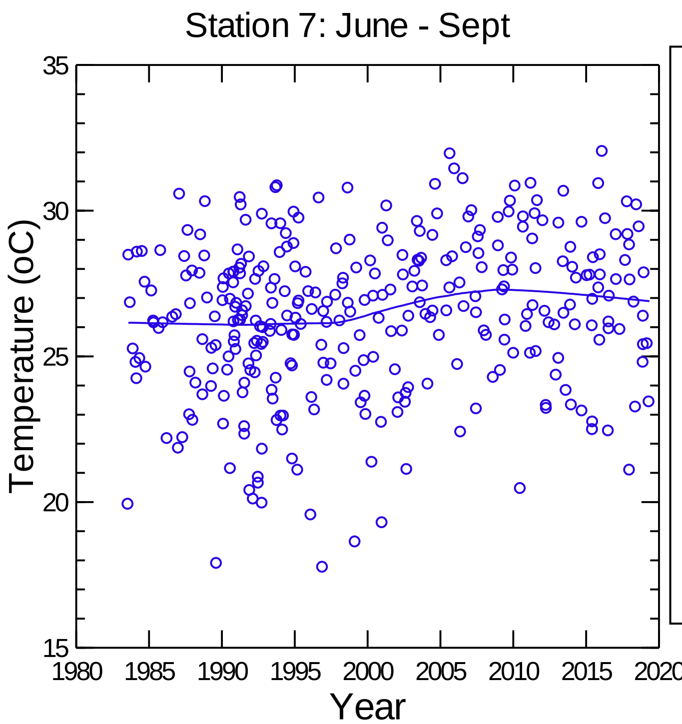
Significance column indicates the probability that a correlation coefficient this large could be due to chance alone. If this probability is greater than 0.05, then NS (not significant) is indicated. Both near surface and near bottom samples included.

Table 17
Correlation and Linear Regression Coefficients
Water Quality Parameter vs. Year for 1983-2019
Fairfax County Environmental Laboratory Data
June-September

Parameter	Station 7 Corr. Coeff.	Station 7 Reg. Coeff.	Station 7 Signif.	Station 9 Corr. Coeff.	Station 9 Reg. Coeff.	Station 9 Signif.
Chloride	0.024	-----	NS	0.052	-----	NS
Lab pH	0.525	-0.034	<0.001	0.355	-0.017	<0.001
Alkalinity	0.124	0.147	0.005	0.384	0.483	<0.001
BOD	0.641	-0.150	<0.001	0.400	-0.041	<0.001
Total Suspended Solids	0.373	-0.881	<0.001	0.197	-0.107	0.002
Volatile Suspended Solids	0.412	-0.578	<0.001	0.385	-0.120	<0.001
Total Phosphorus	0.582	-0.003	<0.001	0.339	-0.001	<0.001
Soluble Reactive Phosphorus	0.108	-0.0001	0.015	0.063	-----	NS
Ammonia Nitrogen	0.318	-0.016	<0.001	0.279	-0.002	<0.001
Nitrite Nitrogen	0.447	-0.003	<0.001	0.158	-0.001	<0.001
Nitrate Nitrogen	0.591	-0.032	<0.001	0.623	-0.031	<0.001
Organic Nitrogen	0.599	-0.045	<0.001	0.396	-0.012	<0.001
N to P Ratio	0.233	-0.256	<0.001	0.438	-0.353	<0.001

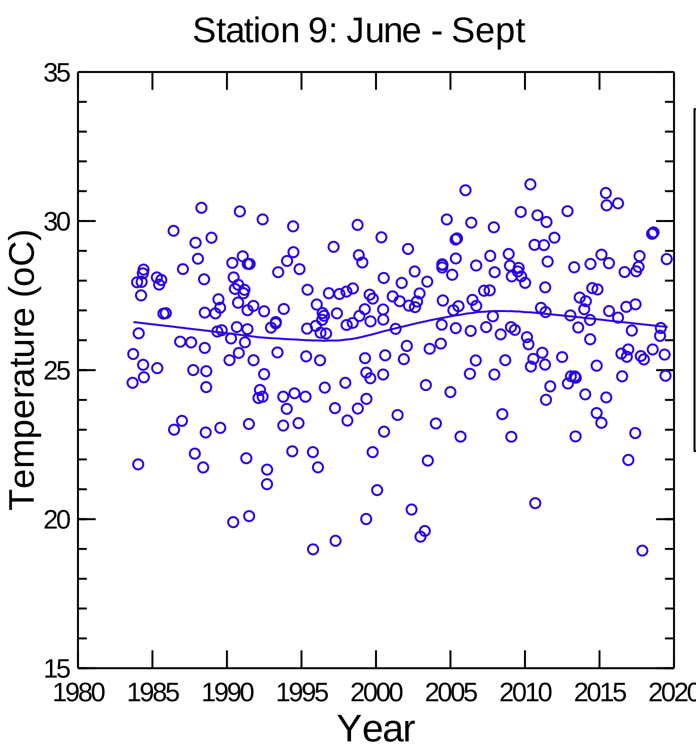
For Station 7, both surface and bottom samples used, n=479-522 except Nitrite Nitrogen where n=444
For Station 9, only surface samples used, n=238-262 except Nitrite Nitrogen where n =223.

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.



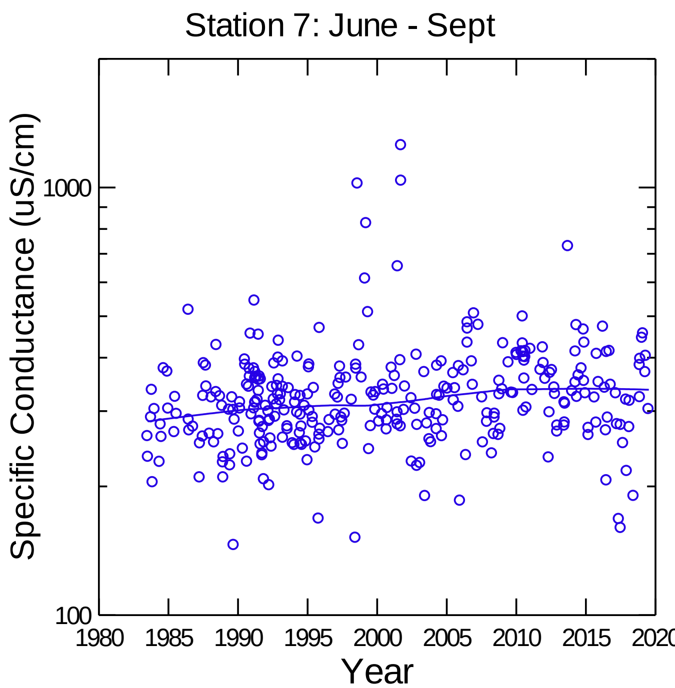
Water temperatures during the summer months generally varied between 20ºC and 30ºC over the study period (Figure 78). The LOWESS curve indicated an average of about 26°C during the period 1984-2000 with a slight upward trend in the last few years to about 27ºC. Linear regression analysis indicated a significant linear trend in water temperature in the cove when the entire period of record is considered (Table 16). 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.



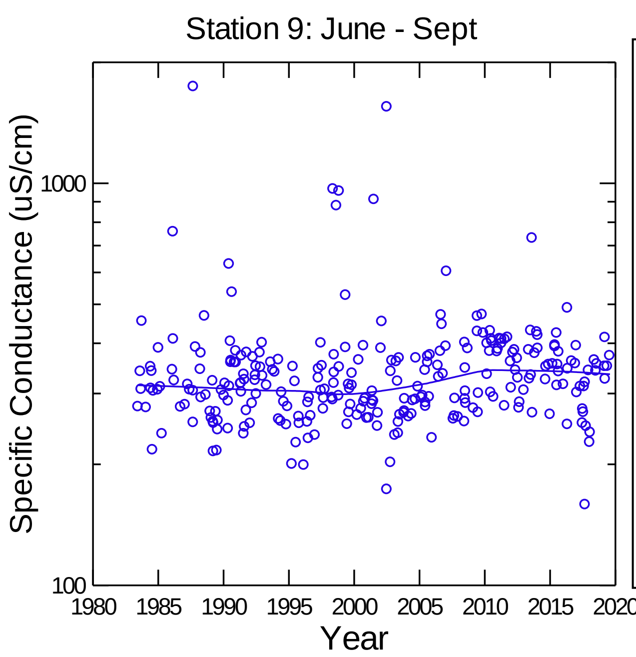
In the river summer temperatures have been similar to those in the cove with fewer readings above 30°C in the river (Figure 79). The long term trend was not significantly different from 0 in the river (Table 16).

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



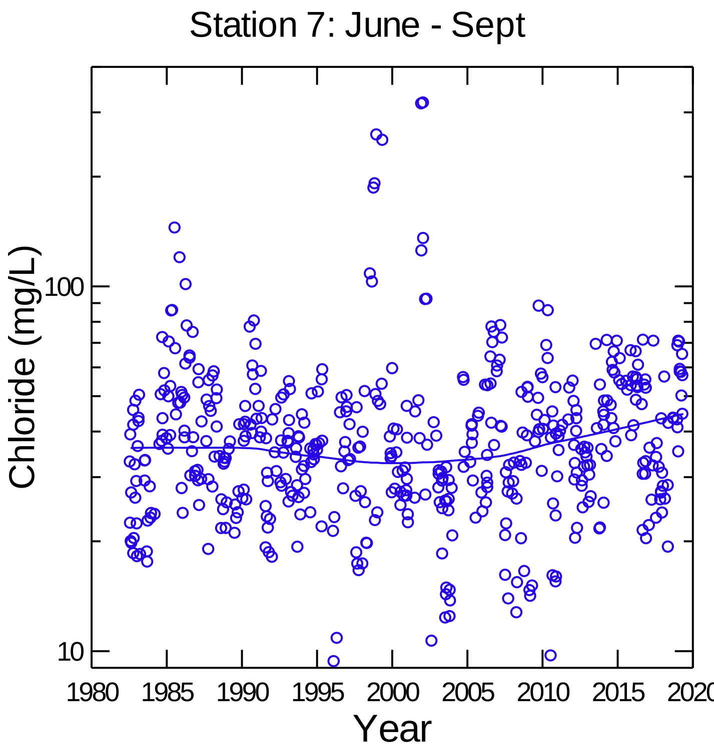
Specific conductance was generally in the range 200-500 µS/cm over the study period (Figure 80). Some significantly higher readings have been observed sporadically. A slight increase in specific conductance was suggested by the LOWESS line over the study period. This was confirmed by linear regression analysis which found a significant linear increase of 1.5 µS/cm per year over the long term study period (Table 16). This would yield a total increase of 52 uS/cm over the entire study

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



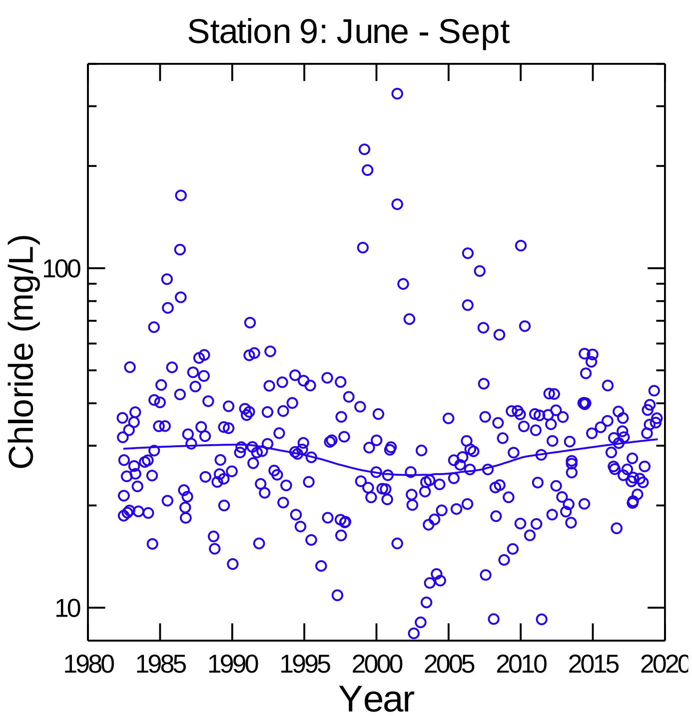
Conductivity values in the river were in the same general range as in the cove (Figure 81). Most values were between 200 and 500 µS/cm with a few much higher values. These higher values are probably attributable to intrusions of brackish water from downstream during years of low river flow. Linear regression did not reveal a significant trend in river conductivity (Table 16).

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



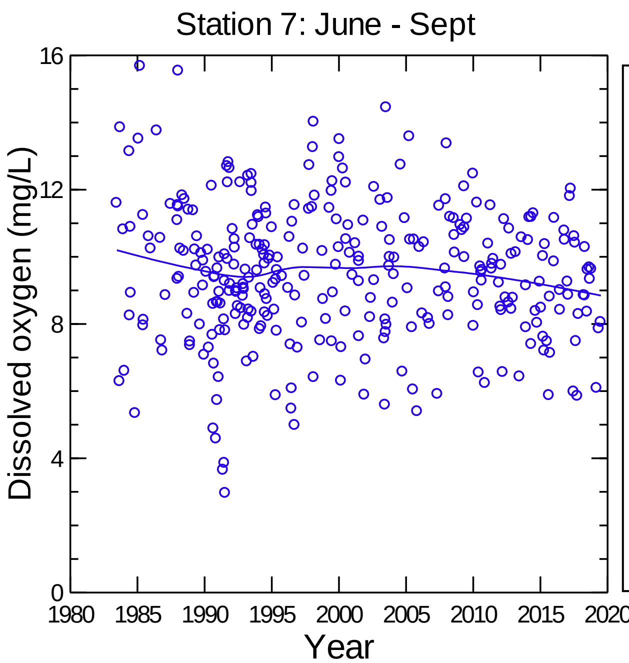
Chloride levels were clustered in a relatively narrow range of 20-70 mg/L for the entire study period (Figure 82). Higher values observed in some years were probably due to the estuarine water intrusions that occur in dry years. The trend line is nearly flat and a linear regression was not statistically significant (Table 17).

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



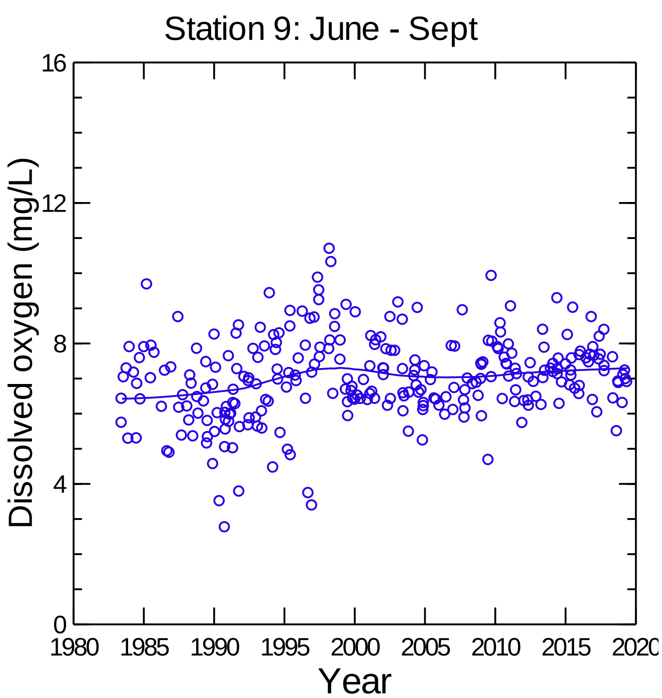
Chloride in the river has been slightly more variable than that in the cove, but in the same general range (Figure 83). The higher readings are again due to brackish water intrusions in dry years. A slight trend of increasing values in the 1980’s followed by decreases in the 1990’s and increases since 2005 was suggested by the LOWESS trend line. However, temporal linear regression analysis was not statistically significant (Table 17).

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



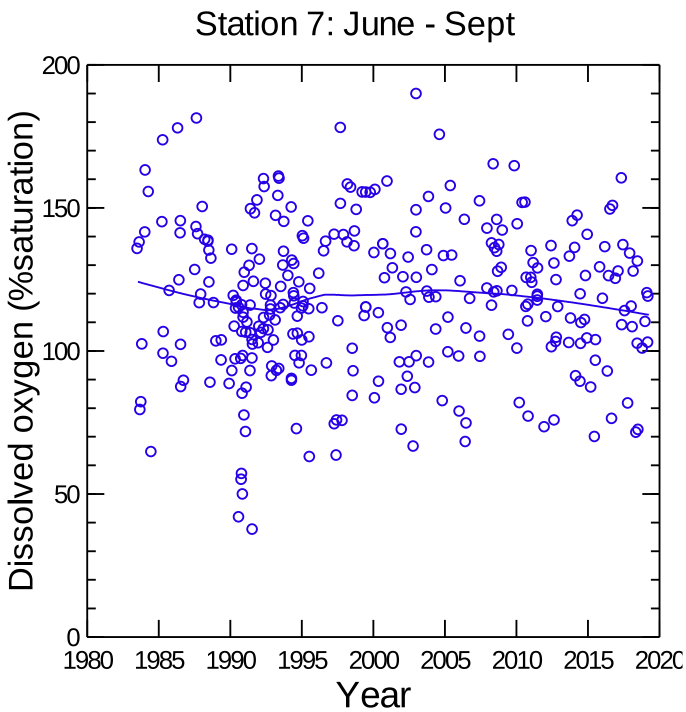
Dissolved oxygen in the cove has generally been in the range 7-13 mg/L during the summer months (Figure 84). A slight downward trend was observed through 1990, but since then the trend line has flattened, suggesting little consistent change and a mean of about 9-10 mg/L. In the cove dissolved oxygen (mg/L) did not exhibit a significant linear trend over the long term study period (Table 16).

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



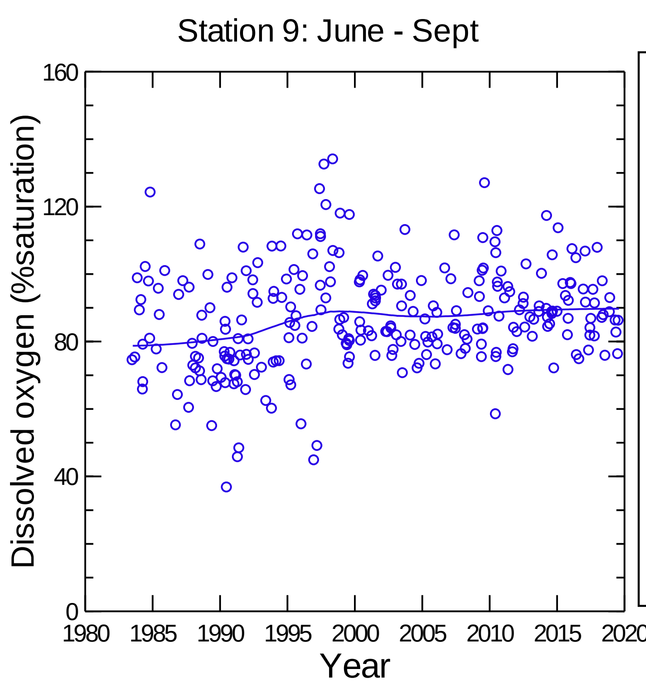
In the river dissolved oxygen values generally were in the range 5-9 mg/L over the long term study period (Figure 85). The LOWESS trend line some subtle changes from year to year, but little consistent pattern. The linear regression analysis over the entire period indicated a significant positive trend with slope of 0.022 mg/L per year or 0.8 mg/L over the period of record (Table 16).

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



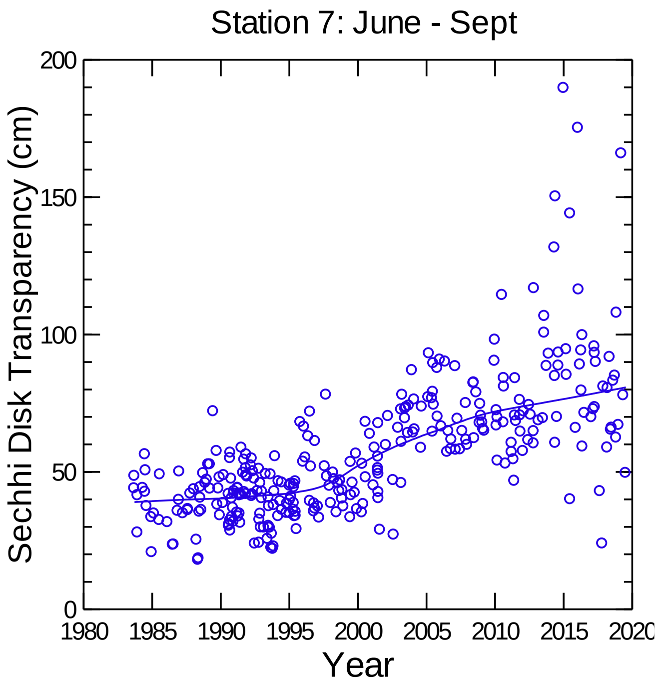
Dissolved oxygen was generally in the range 100-150% saturation in the cove over the long-term study period indicating the importance of photosynthesis in the cove (Figure 86). A decline was indicated by the trend line through 1990 followed by a slight recovery in subsequent years. Percent saturation DO did not exhibit a significant linear trend over the long-term study period (Table 16). 2019 values fell around the trend line.

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



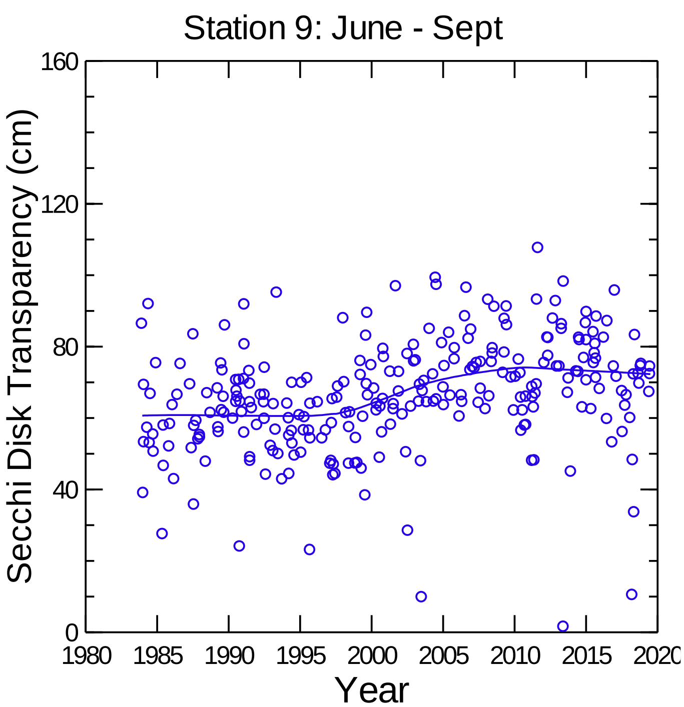
In the river dissolved oxygen was generally less than 100% indicating that photosynthesis was much less important in the river than in the cove and that respiration dominated (Figure 87). The trend line showed a very gradual increase which was statistically significant as indicated by regression analysis with a slope of 0.32% per year or about 11% over the course of the study (Table 16). 2019 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.



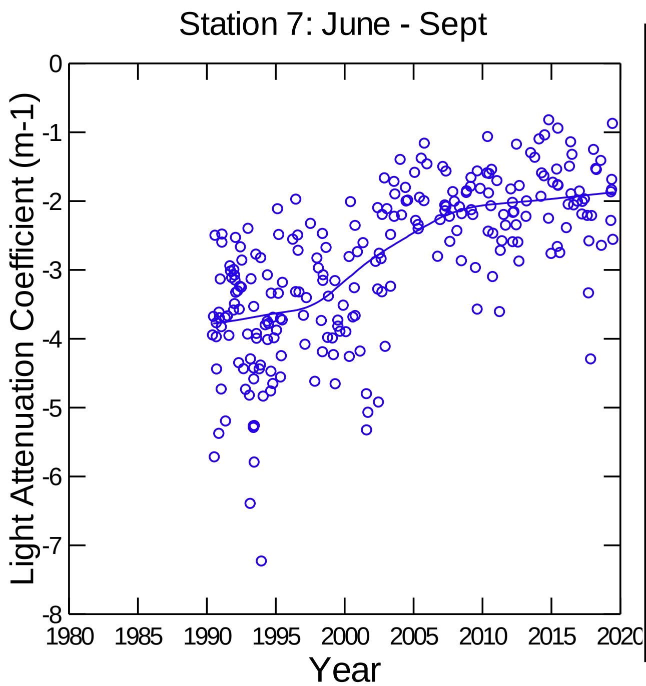
Secchi disk transparency is a measure of water clarity. Secchi disk was fairly constant from 1984 through 1995 with the trend line at about 40 cm (Figure 88). Since 1995 there has been a steady increase in the trend line from 40 cm to 80 cm in 2019. Linear regression was highly significant with a predicted increase of 1.7 cm per year or a total of nearly 60 cm over the study period (Table 16).

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



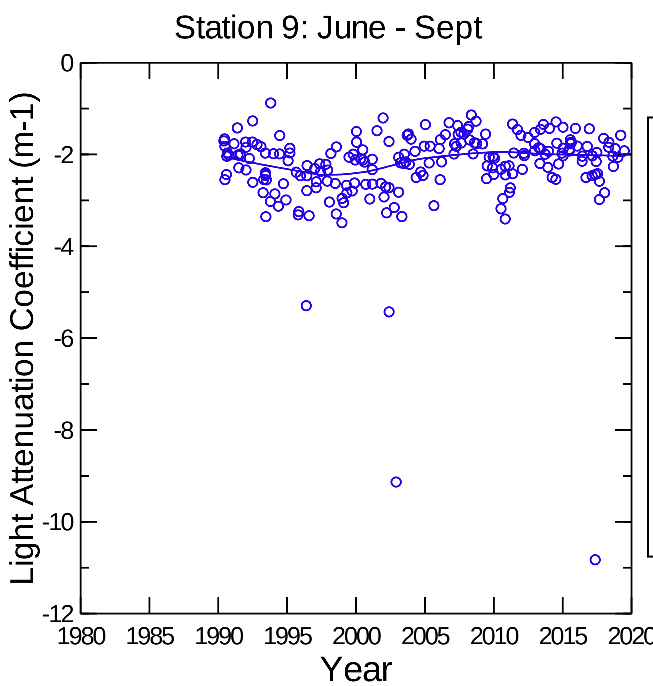
In the river Secchi depth was somewhat greater than in the cove in the 1980's (Figure 89). The trend line was fairly constant at about 60 cm until about 2000. A rise to about 75 cm was observed by 2005 where it has remained. Linear regression revealed a significant increase of 0.47 cm per year with total increase of 16 cm predicted over of the study period (Table 16). Observations in 2019 were near the trend line.

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



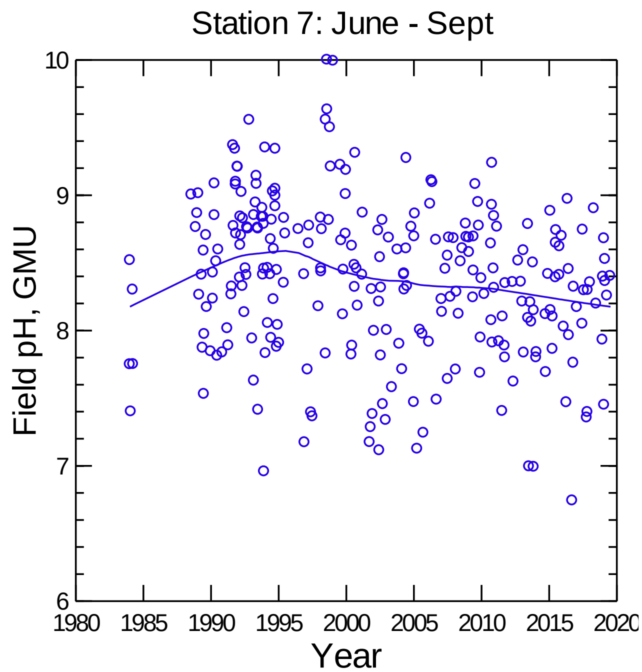
Light attenuation coefficient, another measure of water clarity, reinforces the conclusion that water clarity has been improving in the cove since 1995 (Figure 90). Trend line for the coefficient rose from about -4 to -2 m^{-1} during this time. Values in 2019 were near the trend line. Regression analysis revealed a significant linear increase in light attenuation coefficient over the period 1991-2019 with a slope of 0.085 per year yielding a prediction that light attenuation improved by about 2.4 units over this period (Table 16).

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



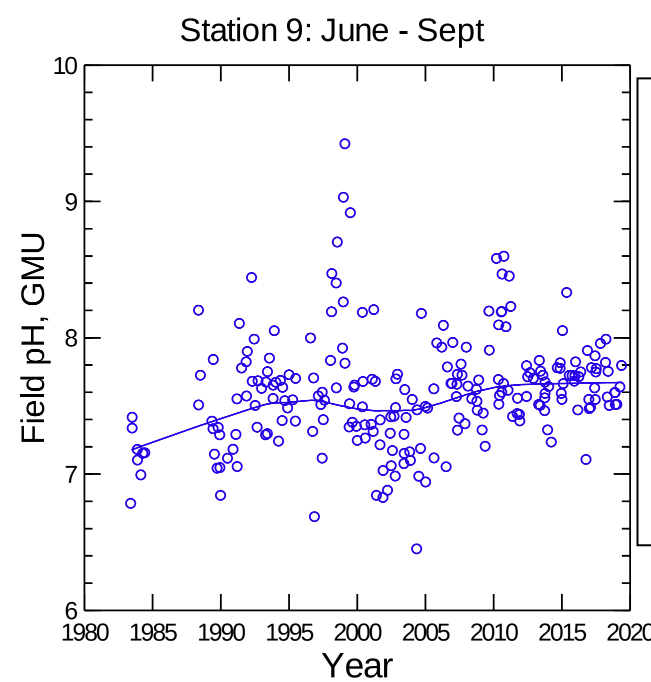
In the river light attenuation coefficient suggested a decline in light transparency between 1991 and 1997 followed by an increase through about 2008 (Figure 91). Between 2008 and 2016 the trend line indicates that light transparency has held fairly constant. Regression did not produce a significant slope over the period (Table 16).

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



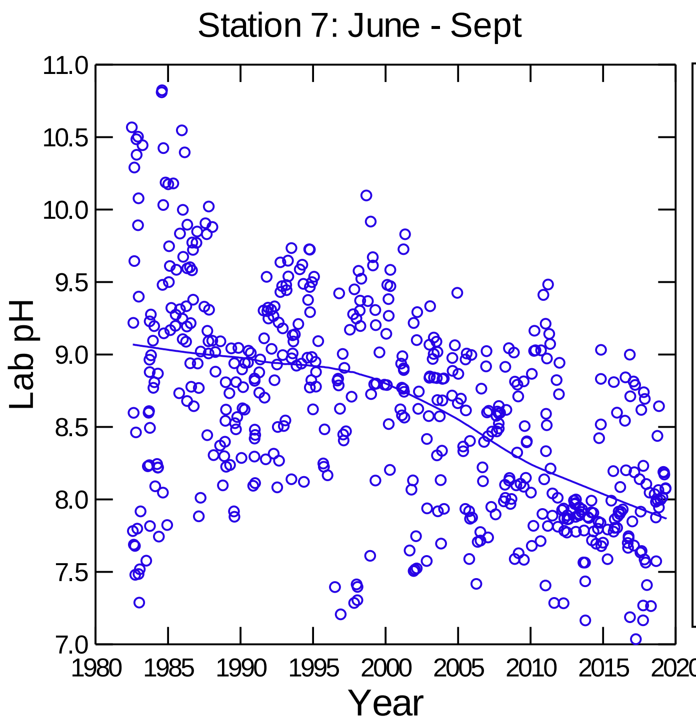
Field pH has not been measured as consistently over the entire study period as other parameters. Cove values have generally been in the 8-9 range. There is a clear trend of decreasing values since 1995 (Figure 92). Linear regression analysis now gives some evidence of a declining linear trend with a slope of -0.012 units per year when the entire study period was considered (Table 16).

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



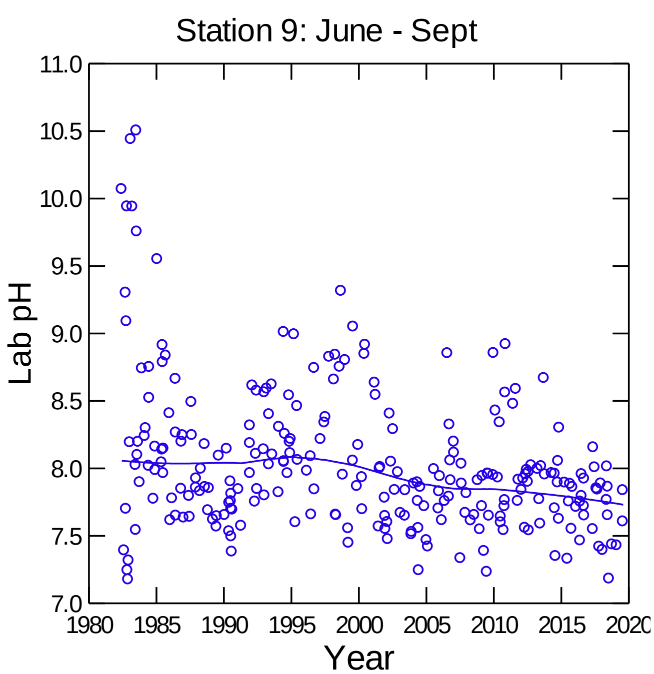
In the river a different pattern has been observed over this period (Figure 93). pH in the river has been consistently lower by about 1 pH unit than in the cove. If anything, the trend line has shown a tendency to increase. When all years were considered, field pH in the river shows a significant increase at a rate of 0.008 units per year (Table 16).

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



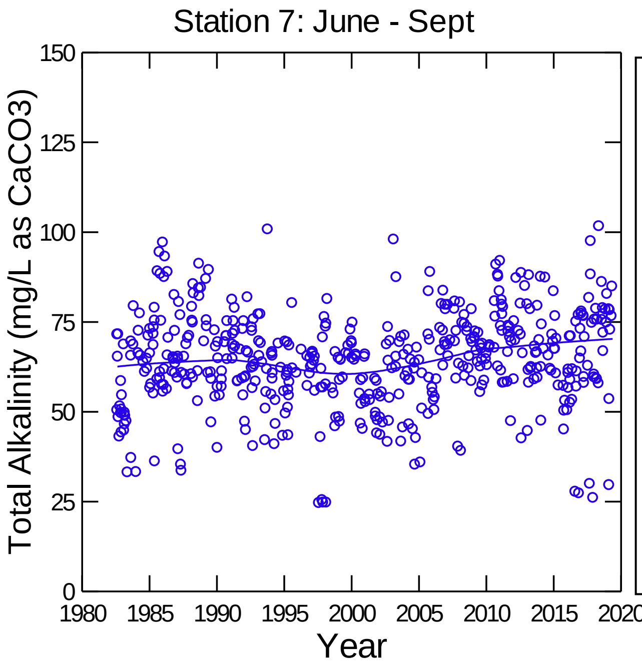
Lab pH as measured by Fairfax County personnel has shown a clear decline, especially (Figure 94). Since 2000 a decline is very evident with the trend line decreasing from about 9.0 to about 7.8. Linear regression indicates a significant decline in lab pH over the study period at a rate of about 0.034 pH units per year or a total of 1.2 units over the study period (Table 17). 2019 data were generally above the trend line.

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



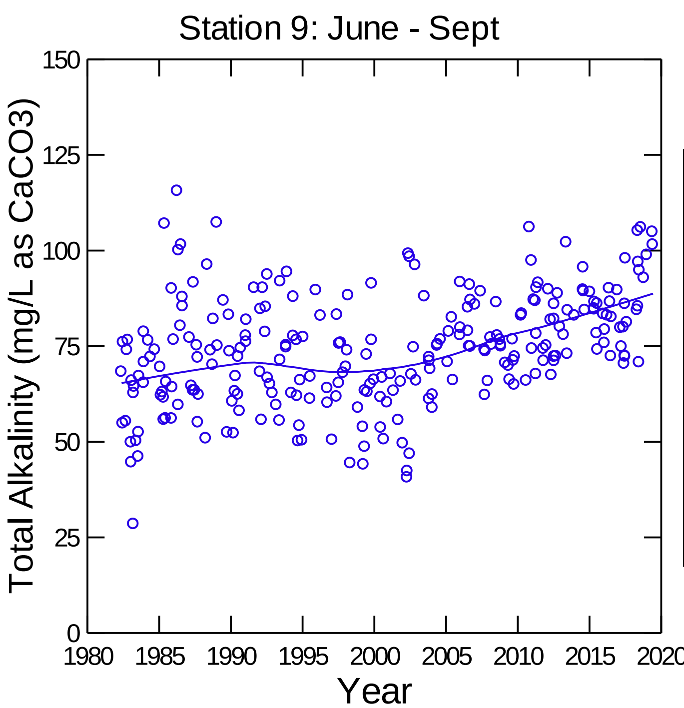
In the river, long term pH trends as measured by Fairfax County lab personnel indicate that most values fell between 7 and 8.5 (Figure 95). The trend line has increased and decreased slightly over the years. pH in the river showed a significant linear decline with a rate of 0.017 per year yielding a total decline of 0.60 units over the long-term study period (Table 17).

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



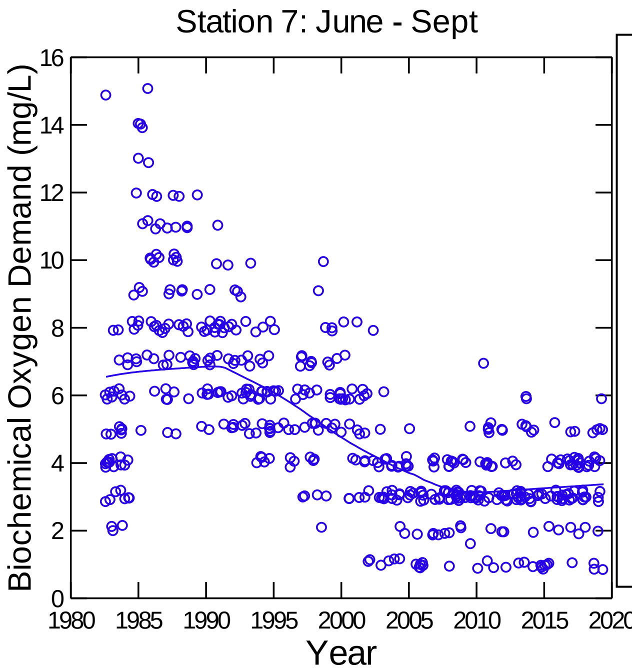
Total alkalinity as measured by Fairfax County personnel exhibited little variation early on and a slow increase since 2000 (Figure 96). The trend line at 2017 was slightly higher than it was in 1983. Overall, a very weak statistically significant linear trend has developed in total alkalinity in the cove over this period with a slope of 0.15 mg/L per year yielding a projected increase of about 5.2 mg/L over the entire study period (Table 17).

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



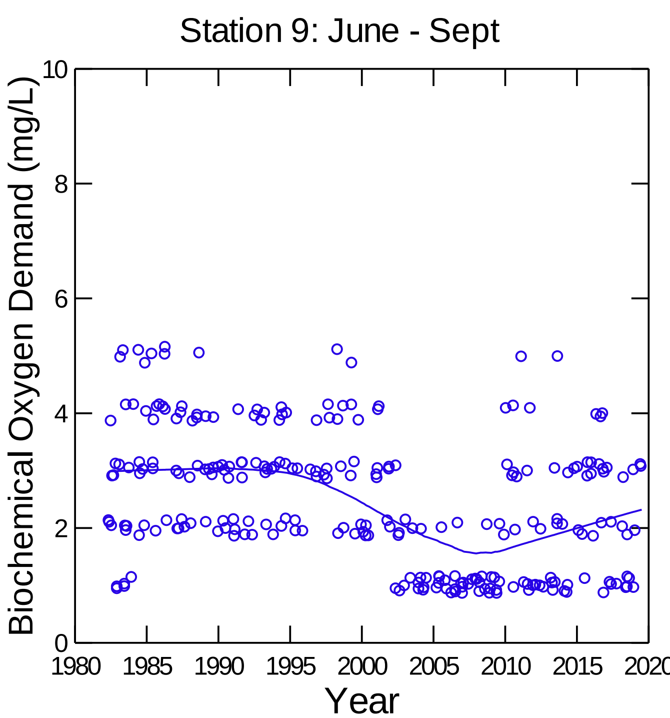
In the river a similar pattern has been observed over the three decades with an even clearer recent increase (Figure 97). There is a significant linear trend over the period with a slope of 0.48 mg/L suggesting a modest increase of about 17 mg/L over the entire study period (Table 17).

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



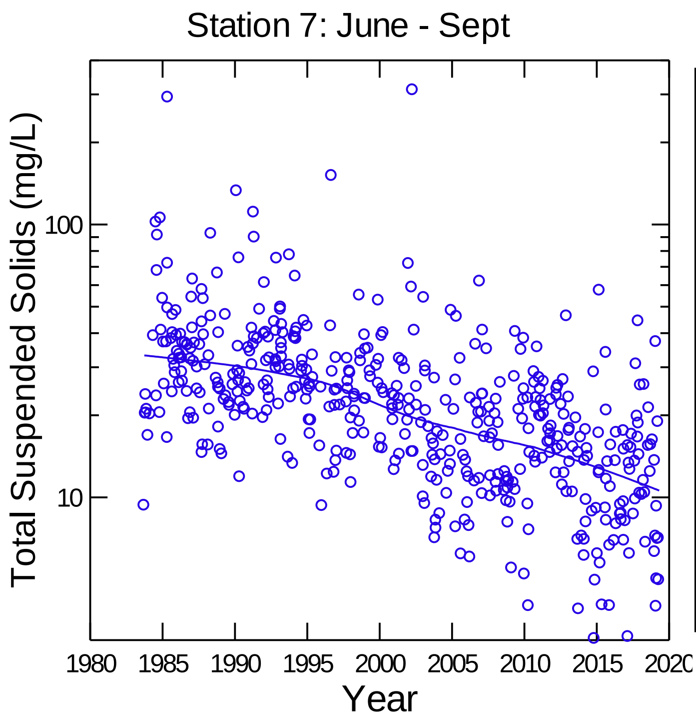
Biochemical oxygen demand has shown a distinct pattern over the long-term study period in Gunston Cove (Figure 98). In the 1980's the trend line rose from about 6 mg/L to 7 mg/L by 1989. Since then there has been a steady decline such that the trend line has dropped back to about 3 mg/L. BOD has shown a significant linear decline over the entire study period at a rate of 0.15 mg/L per year yielding a net decline of about 5.2 mg/L over the entire period of record (Table 17). 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.



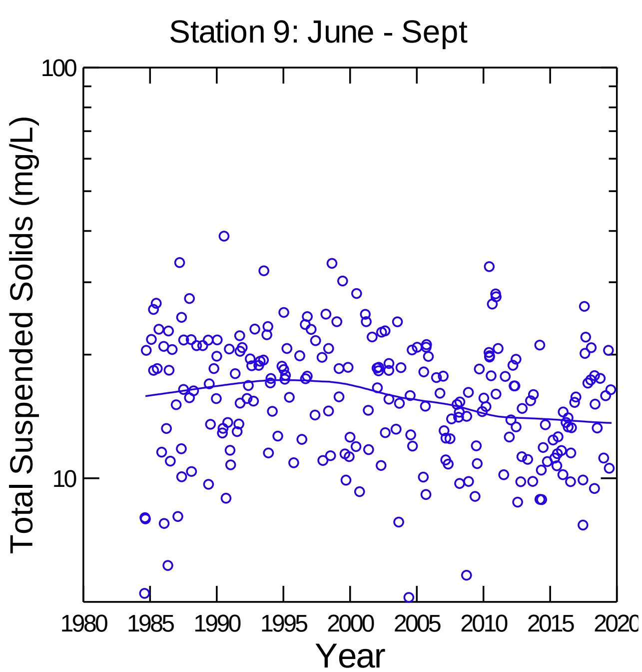
In the river biochemical oxygen demand exhibited a less distinct pattern through the mid 1990's (Figure 99). However, since that time it has decreased somewhat to a trend line value of about 1.0 mg/L. BOD in the river has exhibited a significant linear decrease at a rate of 0.04 units when the entire period of record was considered (Table 17). This would project to an overall decrease of 1.4 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.



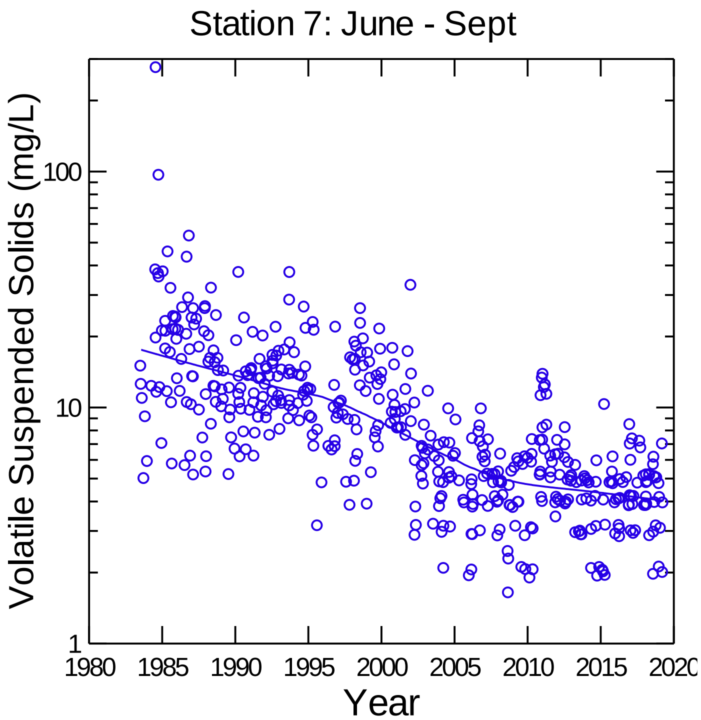
Total suspended solids (TSS) has shown a great deal of variability over the long-term study period. Nonetheless, a decreasing trend in TSS is clear in the cove with the trend line decreasing from about 32 mg/L in 1983 to about 10 mg/L in 2019 (Figure 100). Linear regression was significant indicating a decline of 0.88 mg/L per year yielding a total decline of 31 mg/L since 1984 (Table 17). However, several readings in 2019 were below the trend line.

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



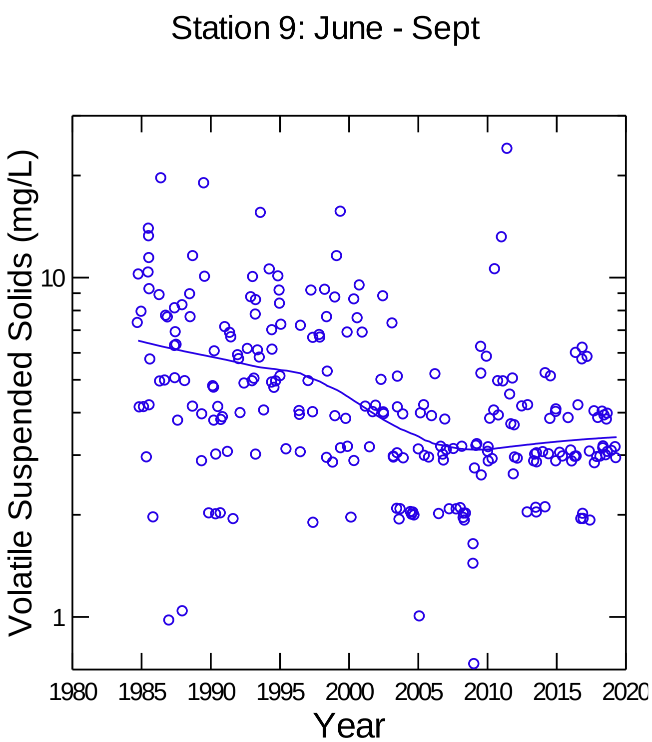
In the river TSS trends have not been as apparent (Figure 101). While much higher values have been observed sporadically, the LOWESS line remained steady at about 18-20 mg/L through most of the period with a slight decrease to about 15 mg/L suggested recently. In the river TSS exhibited a significant 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 17). Most readings in 2019 near the long-term trend line.

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



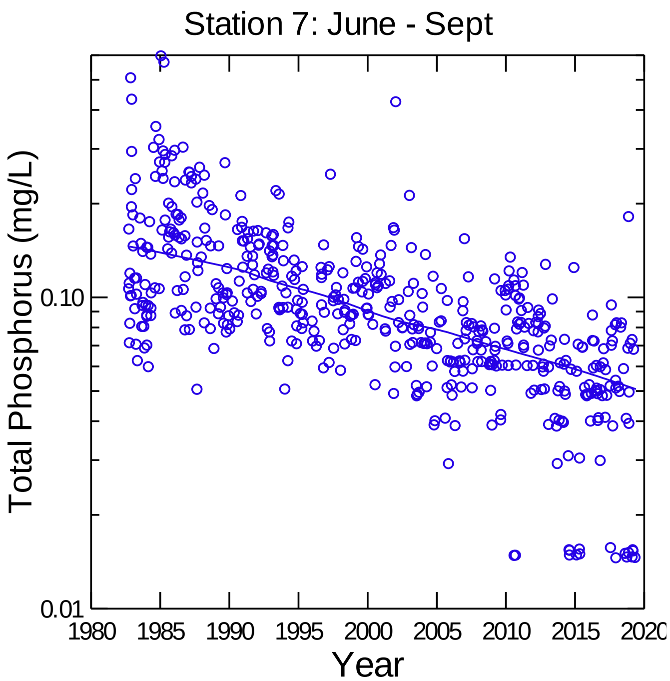
Volatile suspended solids have consistently declined over the study period in the cove (Figure 102). The LOWESS trend line has declined from 20 mg/L in 1984 to about 4 mg/L in 2019. VSS has demonstrated a significant linear decline at a rate of 0.58 mg/L per year or a total of 20 mg/L over the study period (Table 17).

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



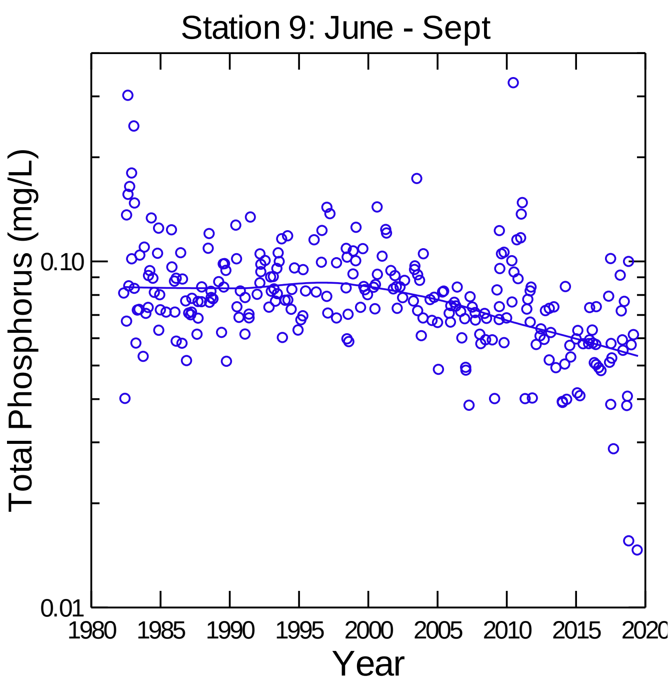
In the river the trend line for volatile suspended solids (VSS) was steady from 1984 through the mid 1990’s, but decreased from 1995 to 2005. Trend line values of about 7 mg/L in 1984 dropped to about 3.5 mg/L by 2018 (Figure 103). VSS in the river demonstrated a significant linear decline at a rate of 0.12 mg/L per year or 4.2 mg/L since 1984 (Table 17).

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



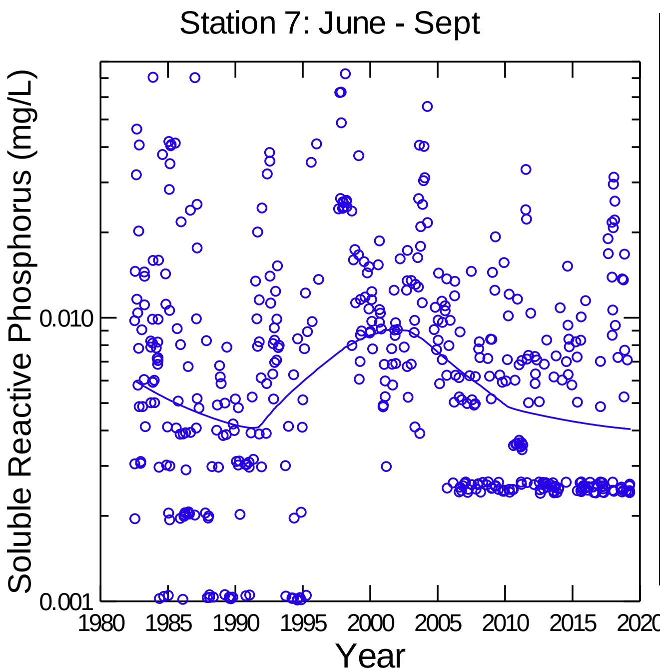
In the cove, total phosphorus (TP) has undergone a consistent steady decline since the late 1980's (Figure 104). By 2019 the trend line had dropped to 0.05 mg/L, more than half of the starting level. Linear regression over the entire period of record indicated a significant linear decline of -0.003 mg/L per year or 0.11 mg/L over the entire study period (Table 17).

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



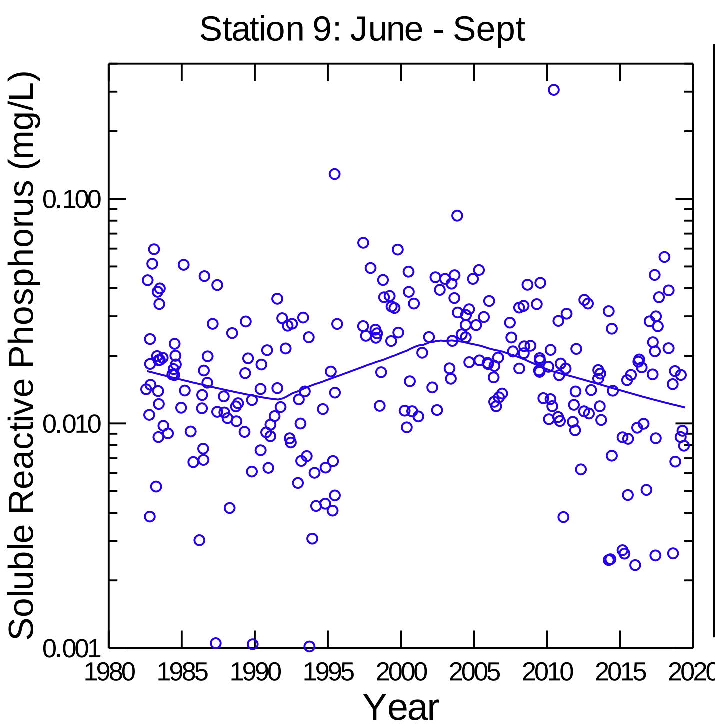
Total phosphorus (TP) values in the river have shown less of a trend over time (Figure 105). Values were steady through about 2000, then declined somewhat. TP exhibited a slight, but significant linear decrease in the river over the long-term study period with a very modest slope of -0.001 mg/L per year (Table 17).

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



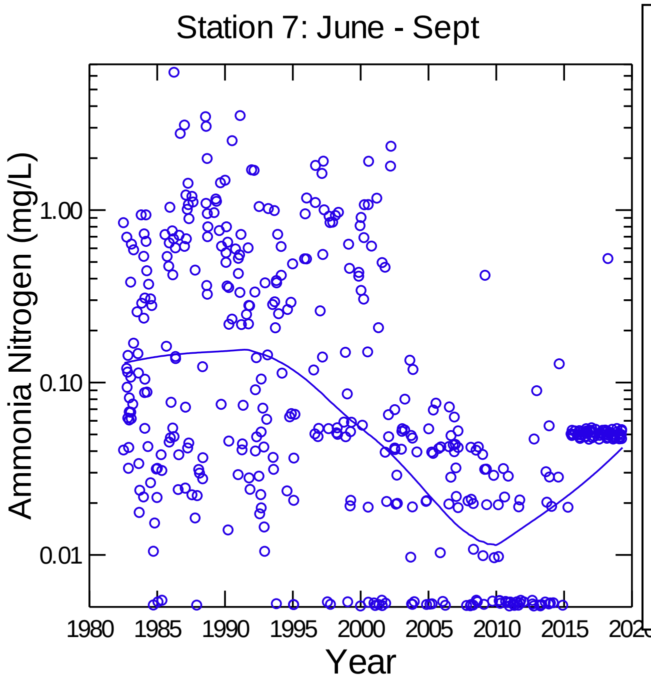
Soluble reactive phosphorus (SRP) declined in the cove during the first few years of the long-term data set, but demonstrated an increase to near its initial level by 2000 (Figure 106). Since then a decline has ensued. (Table 17). One possibility is that less SRP is entering the cove water; another is 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.



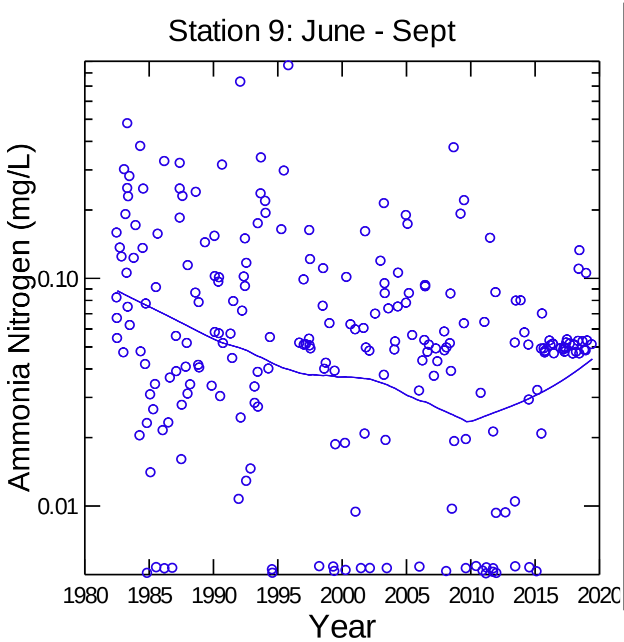
Soluble reactive phosphorus (SRP) in the river has generally been present at higher levels than in the cove, but has undergone a similar decline-resurgence-decline (Figure 107). Linear regression was not significant (Table 17). There were a significant number of non-detect values, but fewer than in the cove.

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



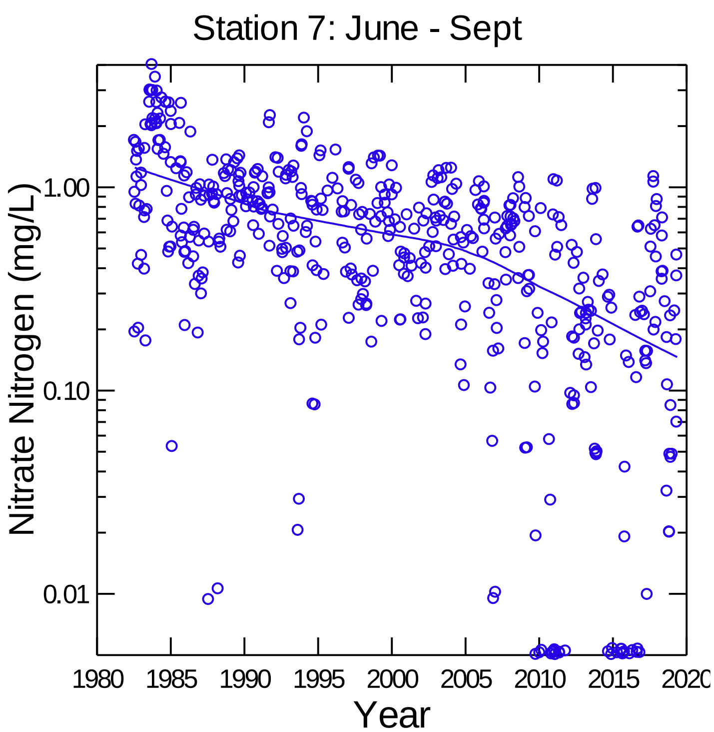
Ammonia nitrogen levels were very variable over the long term study period in the cove, but a trend of decreasing values is evident from the LOWESS trend line (Figure 108). Since 1989 the trend line has decreased from about 0.2 mg/L to about 0.02 mg/L. Linear regression has revealed a significant decline 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 17). Note the increase in values below the detection limit over time (clustered at bottom of graph) and then, more recently, an increase in the detection limit to such a level that it is no longer possible to track trends.

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



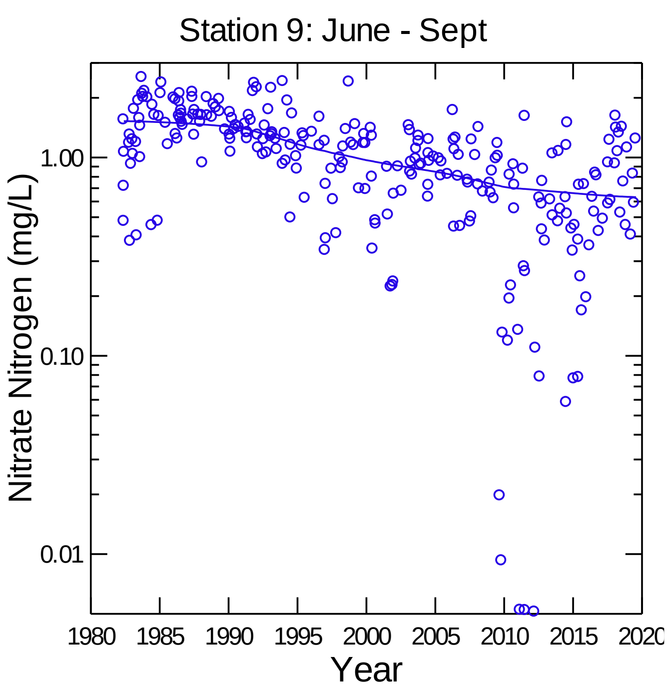
In the river a decreasing trend in ammonia nitrogen has also been observed over most of the study period (Figure 109). Between 1983 and 1999 the trend line dropped from 0.1 mg/L to 0.04 mg/L. Since 1999 it has continued to decline and is now at about 0.02 mg/L. Overall, in the river ammonia nitrogen 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 17). Again, the number of non-detects is increasing and making it impossible to track future trends.

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



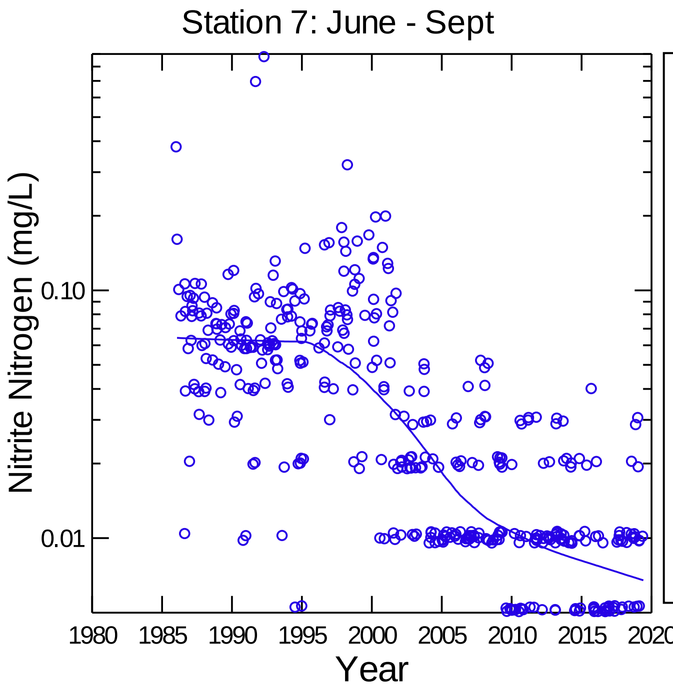
Nitrate nitrogen has demonstrated a steady decline in the cove over the entire period of record (Figure 110). The trend line was at about 1 mg/L in 1983 and by 2019 was below 0.2 mg/L. Linear regression suggested a decline rate of 0.032 mg/L per year yielding a total decline of 1.1 mg/L over the long-term study period (Table 17).

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



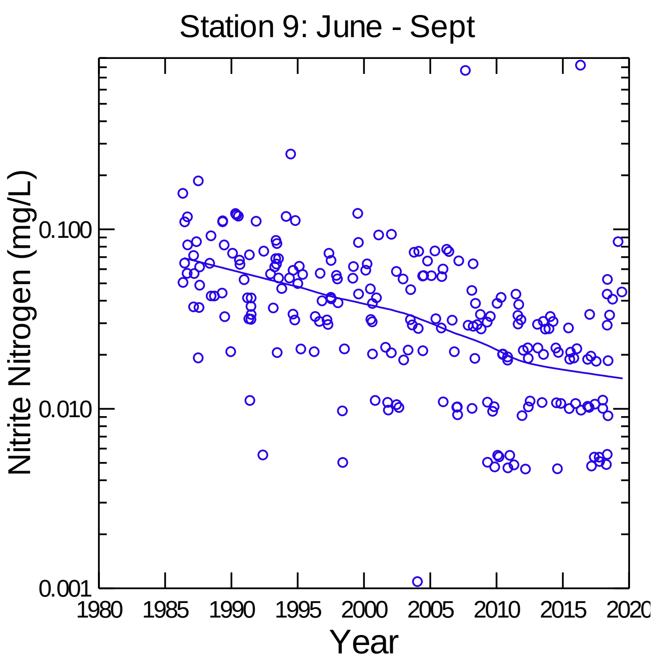
In the river nitrate nitrogen has declined steadily since about 1985 (Figure 111). The trend line dropped from 1.5 mg/L in the mid 1980's to 0.6 mg/L in 2017. Linear regression indicated a rate of decline of -0.031 mg/L per yr which would yielded a 1.1 mg/L decrease in nitrate nitrogen over the study period (Table 17).

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



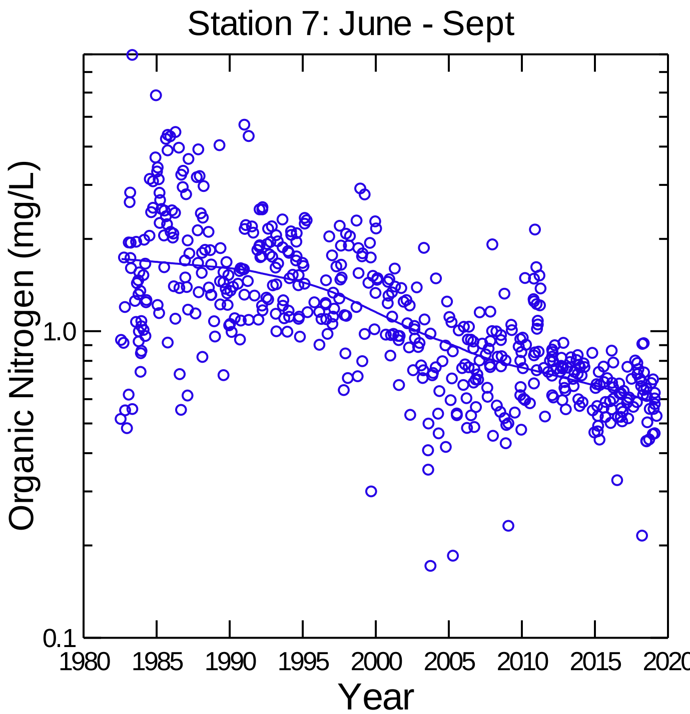
The trend line for nitrite nitrogen indicated steady values at about 0.06-0.07 mg/L through 1999 (Figure 112). Since then there is clear evidence for a decline with the LOWESS line dropping below 0.01 in 2013. Linear regression revealed a significant decline with a slope of 0.003 mg/L per year when the entire period of record was considered (Table 17). 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.



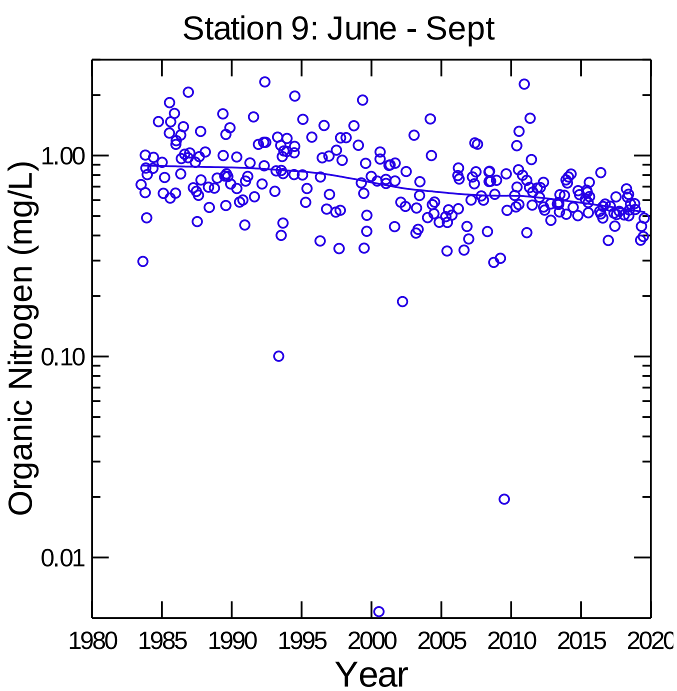
Nitrite nitrogen in the river demonstrated a pattern of decrease during the long term study period (Figure 113). The LOWESS line dropped from 0.07 mg/L in 1986 to less than 0.01 mg/L in 2018. Linear regression indicated a significant linear decline at a rate of 0.001 mg/L per year or 0.03 mg/L over the study period (Table 17).

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



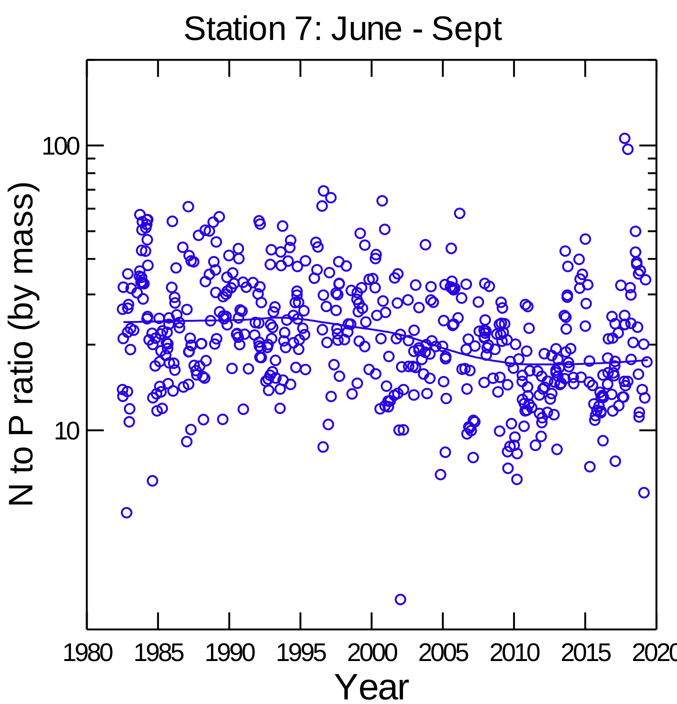
Organic nitrogen in the cove was fairly high in the 1980's and has since undergone a consistent decline through 2019 (Figure 114). In 1983 the trend line was at 1.5 mg/L and dropped below 0.6 mg/L by 2019. Regression analysis indicated a significant decline over the study period at a rate of about 0.045 mg/L per year or a total of 1.6 mg/L over the whole study period (Table 17).

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



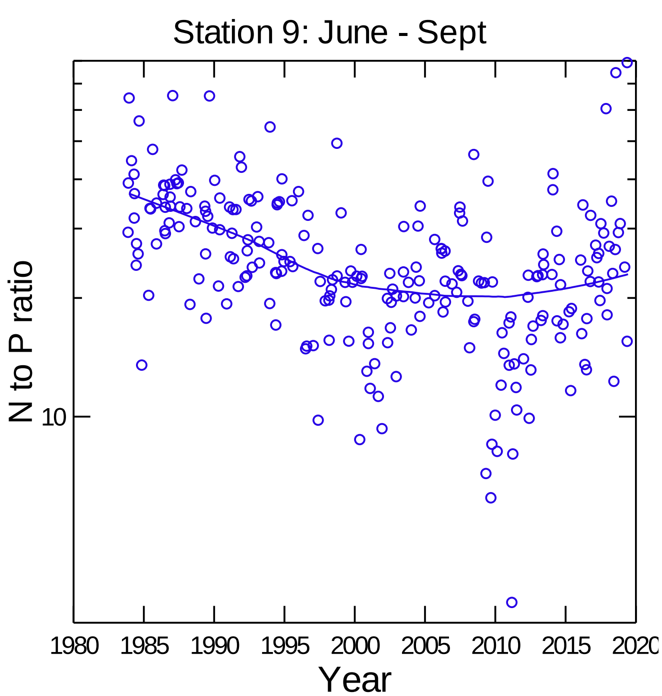
In the river organic nitrogen was steady from 1984 through 1995 and since then has shown perhaps a modest decline (Figure 115). The LOWESS line peaked at about 0.9 mg/L and has dropped to about 0.6 mg/L. Regression analysis indicated a significant linear decline at a rate of 0.01 mg/L when the entire period of record was considered for a total decline of 0.3 mg/L (Table 17).

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 16 by 2019 (Figure 116). Regression analysis over the period of record indicates a statistically significant decline at a rate of 0.26 per year or about 9 units over the entire period (Table 17). This ratio is calculated using nitrate, TKN, and TP values and are less accurate when any of those are below detection limits.

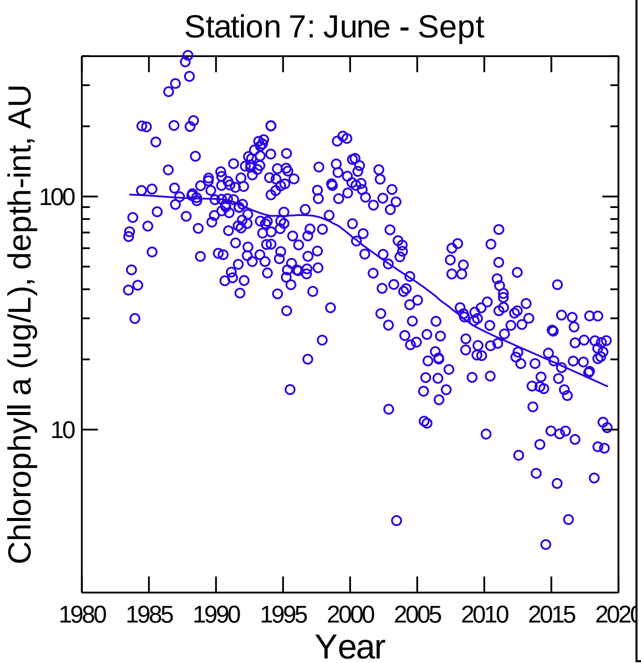
Figure 116. Long term trend in N to P Ratio (Fairfax County Lab Data). Station 7. Gunston Cove.



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 2010 before rising in the last decade. Linear regression analysis confirmed this decline and suggested a rate of 0.35 units per year or a total of 12 units over the long term study period (Table 17).

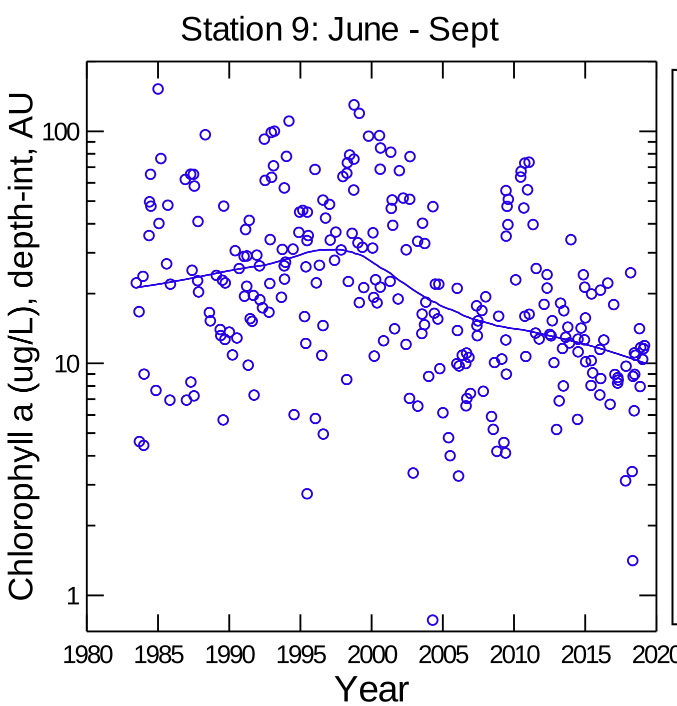
Figure 117. Long term trend in N to P Ratio (Fairfax County Lab Data). Station 9. River mainstem.

C. Phytoplankton Trends: 1984-2019



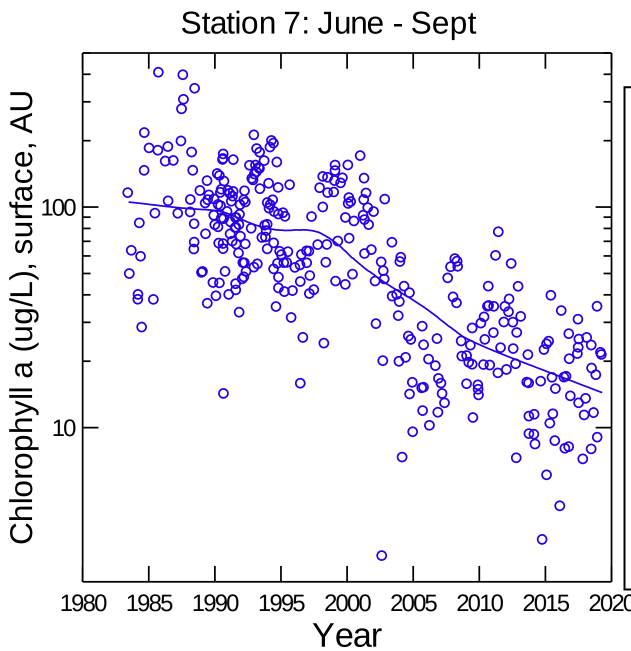
After increasing through much of the 1980's, depth-integrated chlorophyll *a* in the cove demonstrated a gradual decline from 1988 to 2000 and a much stronger decrease since then (Figure 118). The LOWESS line has declined from about 100 µg/L to less than 15 µg/L in 2019. The observed decrease has resulted 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 3.7 µg/L per year or 130 µg/L over the 35-year long term data set (Table 16).

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



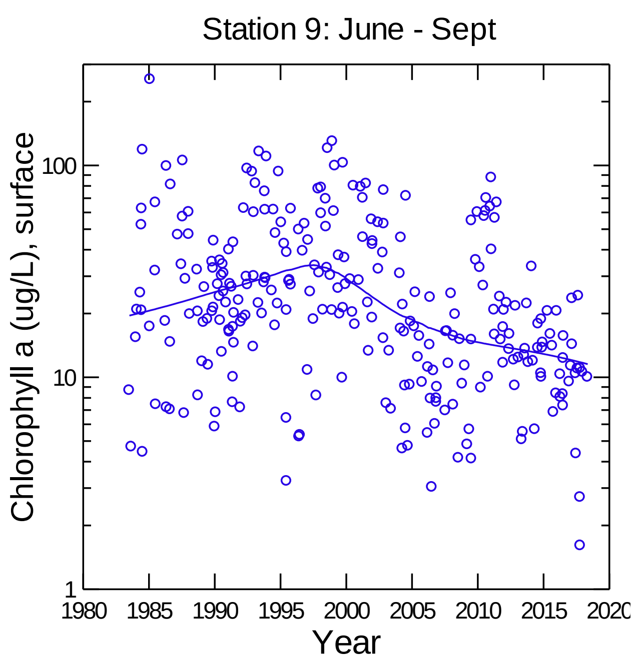
In the river depth-integrated chlorophyll *a* increased gradually through 2000 with the trend line rising from 20 to 30 µg/L (Figure 119). This was followed by a strong decline through reaching about 10 µg/L by 2019. Regression analysis revealed a significant linear decline at a rate of 0.79 µg/L/yr when the entire period is considered (Table 16) 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.



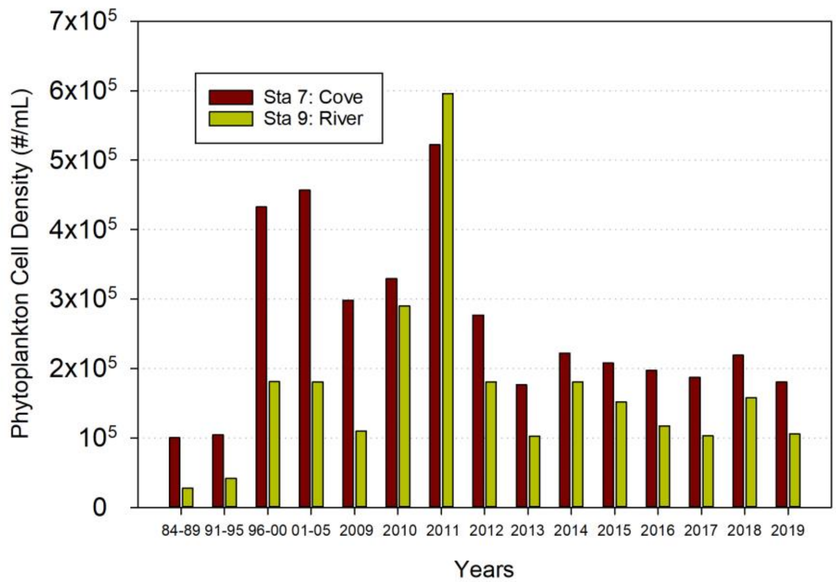
Surface chlorophyll *a* in the cove also exhibited a clear decline over the long-term study period, especially since 2000 (Figure 120). Trend line values of about 100 µg/L in 1988 dropped to less than 15 µg/L in 2018. Linear regression confirmed the linear decline and suggested a rate of 3.7 µg/L per year or 130 µg/L over the entire study (Table 16).

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



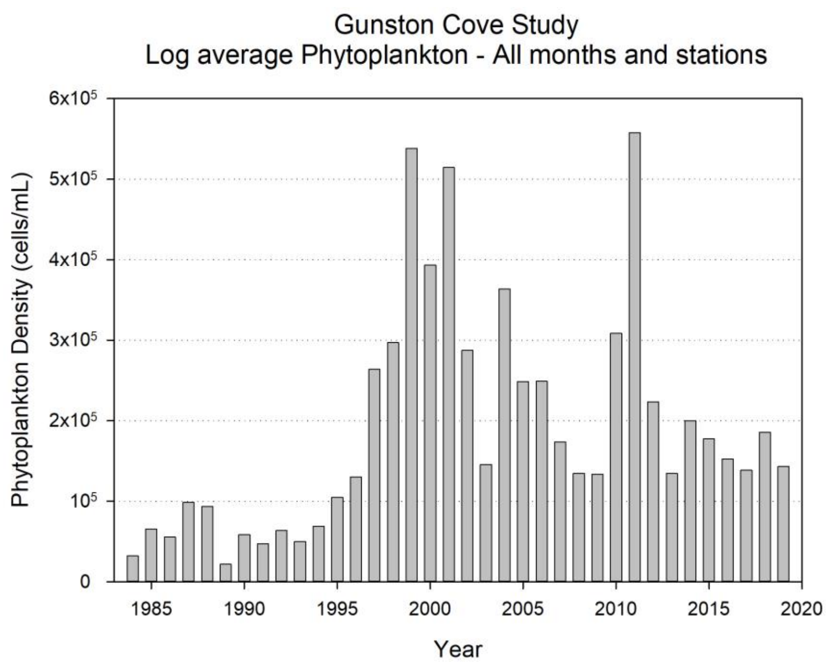
In the river the LOWESS line for surface chlorophyll *a* increased slowly from 1983 to 2000 and then declined markedly through 2019 (Figure 121). Values have stabilized since then at about 12 µg/L. Linear regression revealed a significant decline in surface chlorophyll across this period with a rate of 0.86 µg/L/yr or about 30 µg/L over the whole period (Table 16).

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 2019 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.

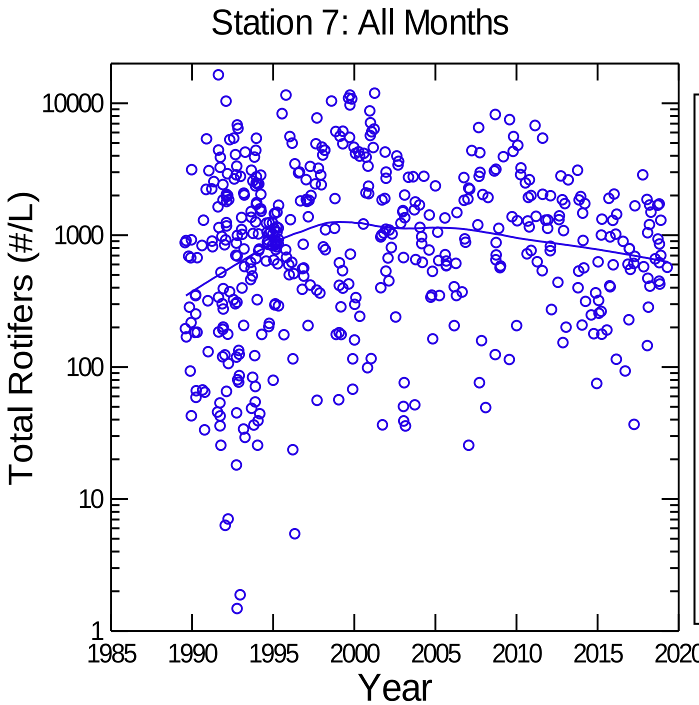
Figure 122. Interannual Comparison of Phytoplankton Density by Region.



By looking at individual years (Figure 123), we see that phytoplankton densities in 2019 remained lower than the high levels observed during the 1995 to 2005 period.

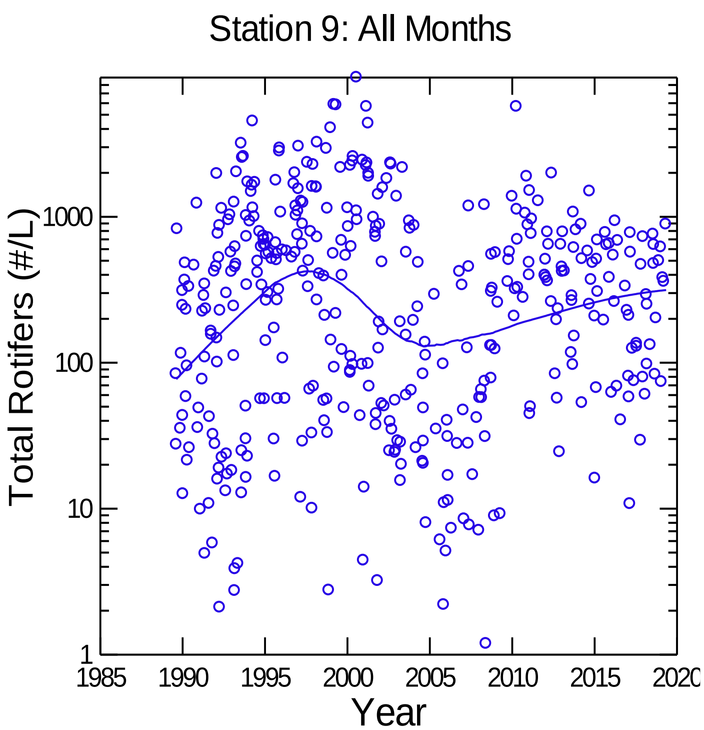
Figure 123. Interannual Trend in Average Phytoplankton Density.

D. Zooplankton Trends: 1990-2019



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 2019, 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.



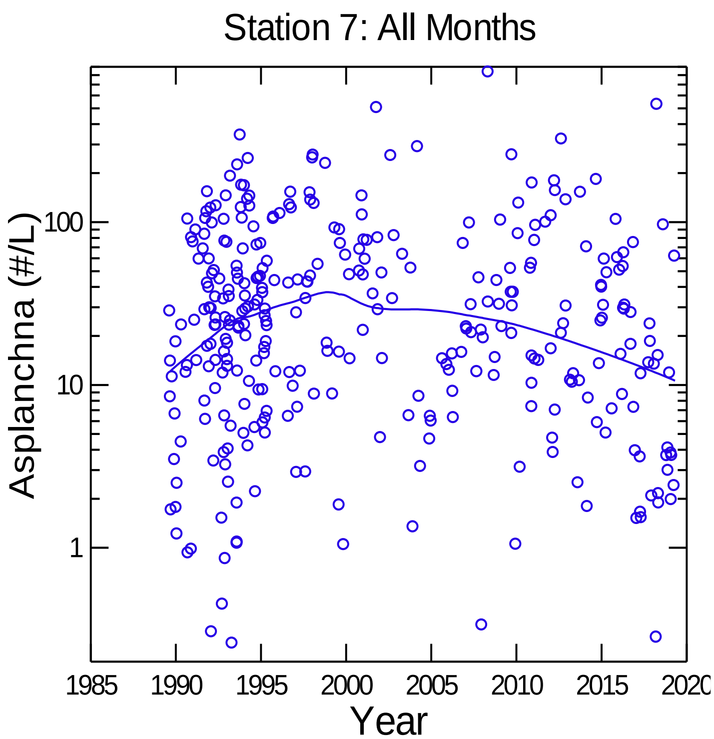
In the Potomac mainstem, rotifers exhibited an initial increase from 1990 to 1998, followed by a decline from 1999 to 2005 and more recently another increase (Figure 125). Trend line values in 1990 were about 80/L and as of 2019 are about 300/L approaching 1998 values. However, when the entire 1990-2018 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 18
Correlation and Linear Regression Coefficients
Zooplankton Parameters vs. Year for 1990-2019
All Nonzero Values Used, All Values Logged to Base 10

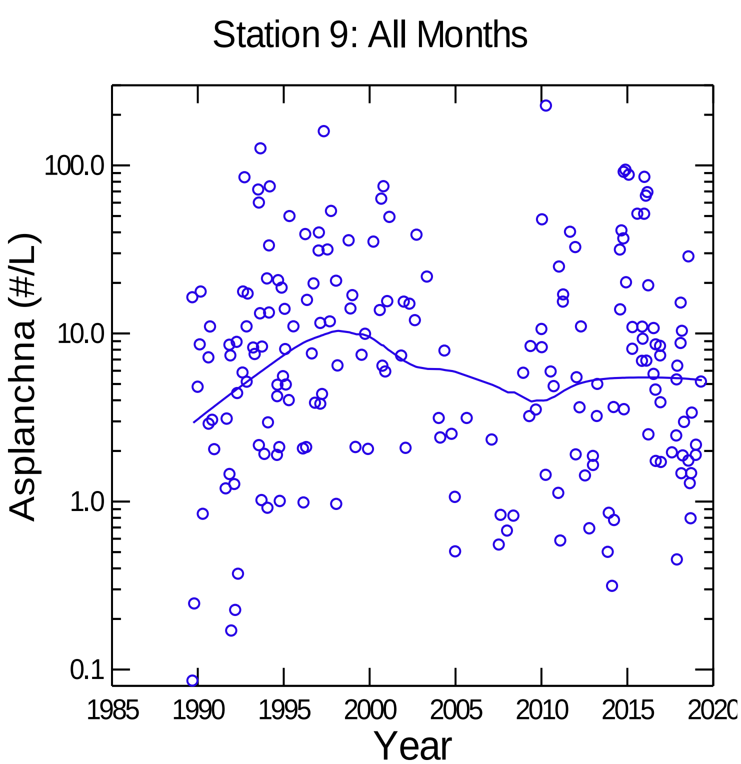
	Station 7			Station 9		
Parameter	Corr. Coeff.	Reg. Coeff.	Signif.	Corr. Coeff.	Reg. Coeff.	Signif.
Asplanchna (m)	0.060 (331)	---	---	0.013 (197)	---	---
Brachionus (m)	0.080 (459)	---	---	0.057 (382)	---	---
Conochilidae (m)	0.045 (398)	---	---	0.116 (317)	-0.011	0.039
Filinia (m)	0.092 (401)	---	---	0.166 (281)	-0.013	0.005
Keratella (m)	0.268 (469)	0.023	<0.001	0.119 (395)	0.011	0.018
Polyarthra (m)	0.090 (441)	---	---	0.018 (353)	---	---
Total Rotifers (m)	0.105 (487)	0.008	0.020	0.030 (407)	---	---
Bosmina (m)	0.091 (285)	---	---	0.093 (339)	---	---
Diaphanosoma (M)	0.243 (386)	-0.036	<0.001	0.238 (291)	-0.029	<0.001
Daphnia (M)	0.102 (300)	---	---	0.144 (204)	-0.014	0.039
Chydorid cladocera (M)	0.034 (271)	---	---	0.013 (192)	---	---
Leptodora (M)	0.293 (227)	-0.032	<0.001	0.384 (169)	-0.037	<0.001
Copepod nauplii (m)	0.409 (466)	0.027	<0.001	0.196 (403)	0.015	<0.001
Calanoid copepods (M)	0.207 (552)	-0.023	<0.001	0.071 (426)	---	---
Cyclopoid copepods (M)	0.094 (514)	-0.011	0.033	0.068 (412)	---	---
Adult and copepodid copepods (M)	0.126 (582)	-0.013	0.002	0.059 (447)	---	---

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.



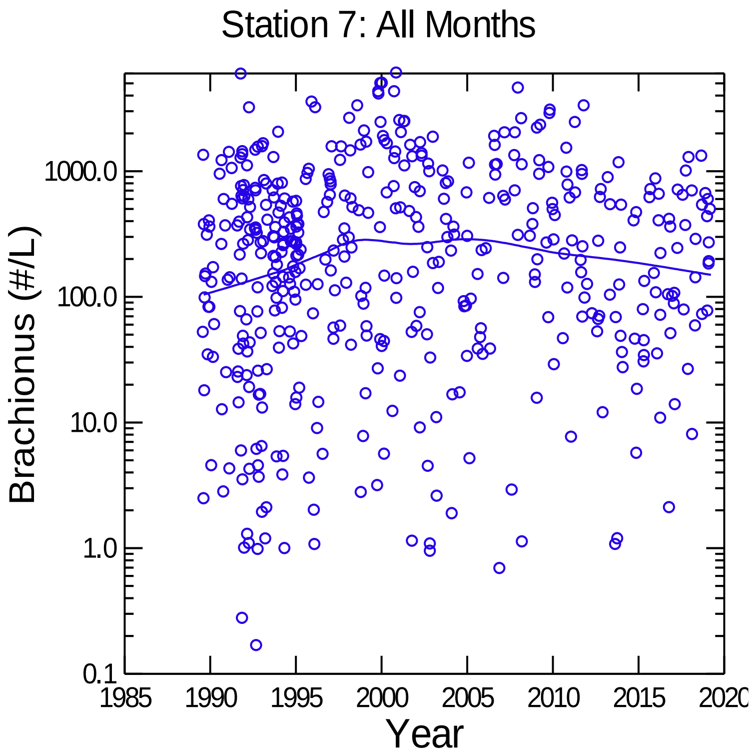
Asplanchna has shown a similar trend as total rotifers at a much lower abundance level (Figure 126). The LOWESS line increased in the 1990's, but has sinced decreased to near initial levels of about 10/L in 2019. No linear trend was found over the study period (Table 18).

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



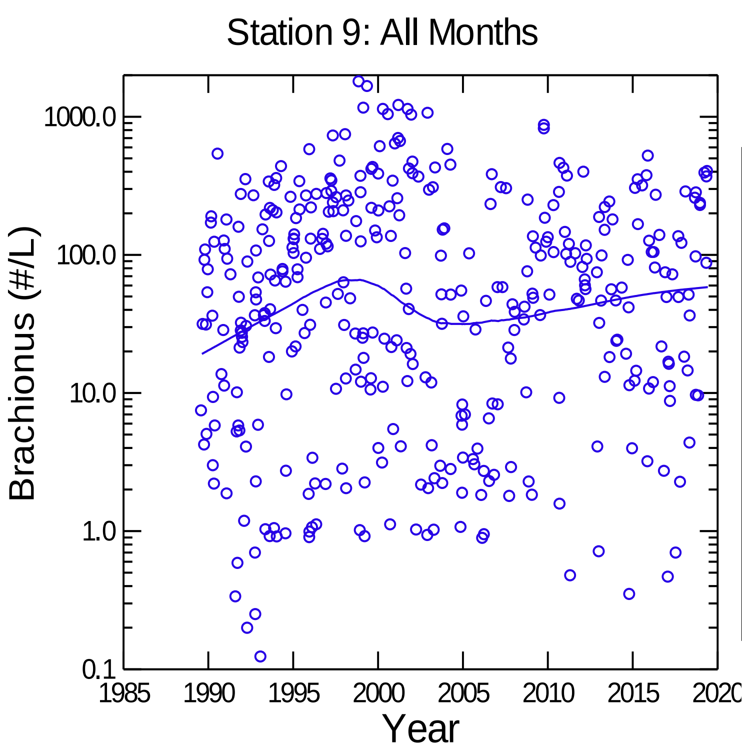
Asplanchna was found at lower densities in the river and the trend line was at about 5/L in 2019 (Figure 127). No linear trend was indicated when the entire study period was considered (Table 18).

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



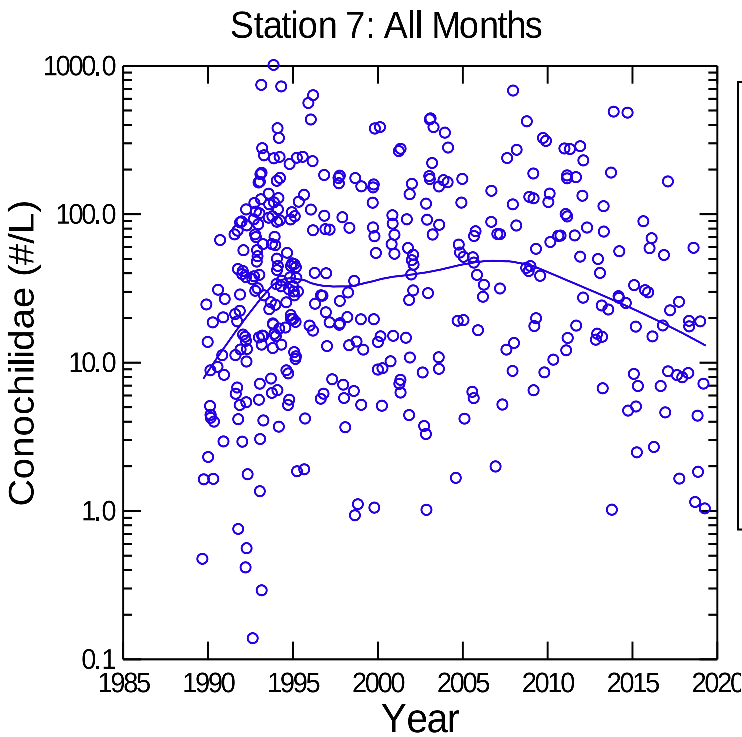
Brachionus is the dominant rotifer in Gunston Cove and the trends in total rotifers are generally mirrored in those in *Brachionus* (Figure 128). The LOWESS line for *Brachionus* suggested about 100/L in 2019, about what was found in 1990. No linear trend was found over the study period (Table 18).

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



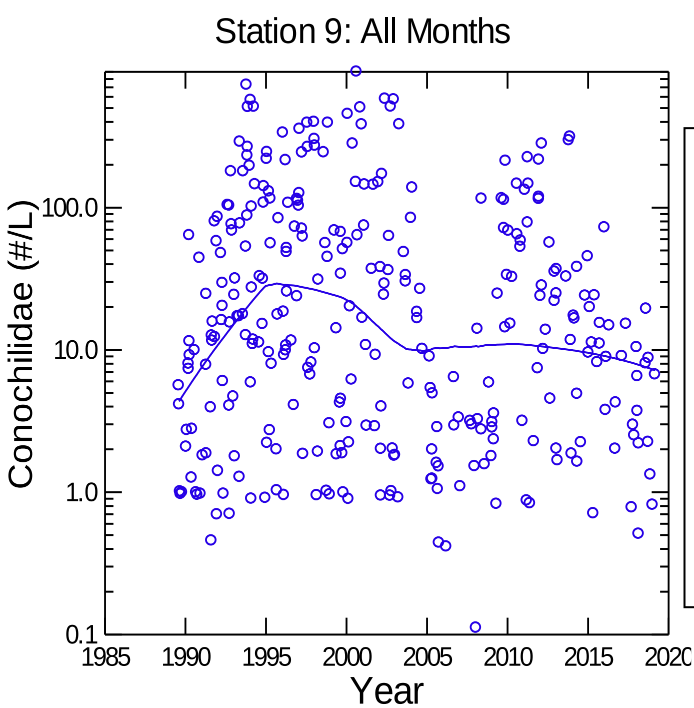
Brachionus was found at lower densities in the river. In the river the LOWESS line for *Brachionus* increased through 2000, but dropped markedly from 2000-2005. Since 2005 a steady increase has been noted with the trend line reaching about 60/L in 2019 (Figure 129). No linear trend was indicated when the entire study period was considered (Table 18).

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



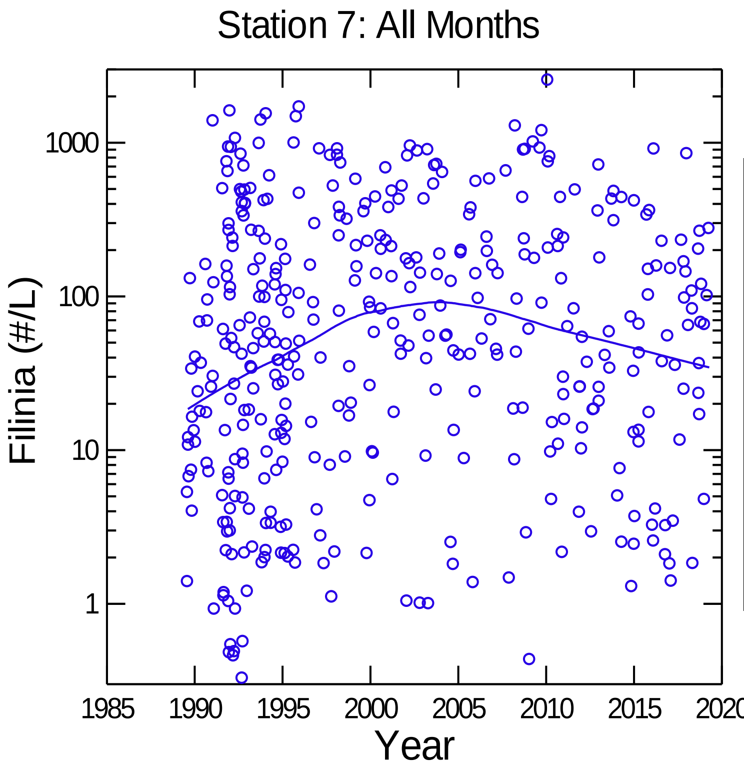
Conochilidae increased strongly from 1990-1995 and since then has leveled off. In 2019 the LOWESS trend line stood at about 13/L (Figure 130). This was well above levels of about 5/L in 1990. Over the entire period of record, a marginally significant linear increase was found (Table 18).

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



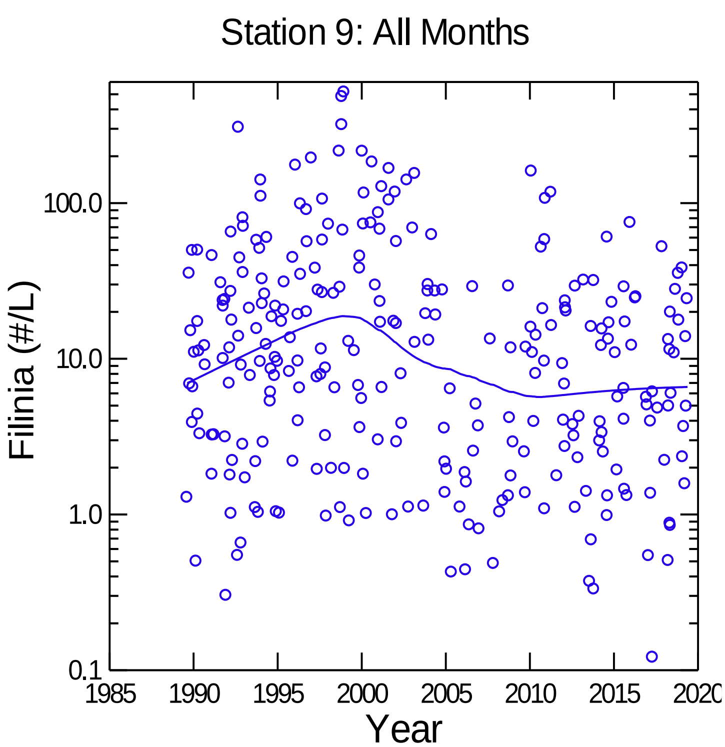
In the river, Conochilidae exhibited a strong increase in the early 1990's similar to that observed in the cove (Figure 131). This was followed by a period of decline and recently a renewed increase. The trend line has gone from 3/L in 1990 to 35/L in 1995 to about 7/L in 2019. When the entire period of record was examined, there was evidence for a significant negative linear trend (Table 18).

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



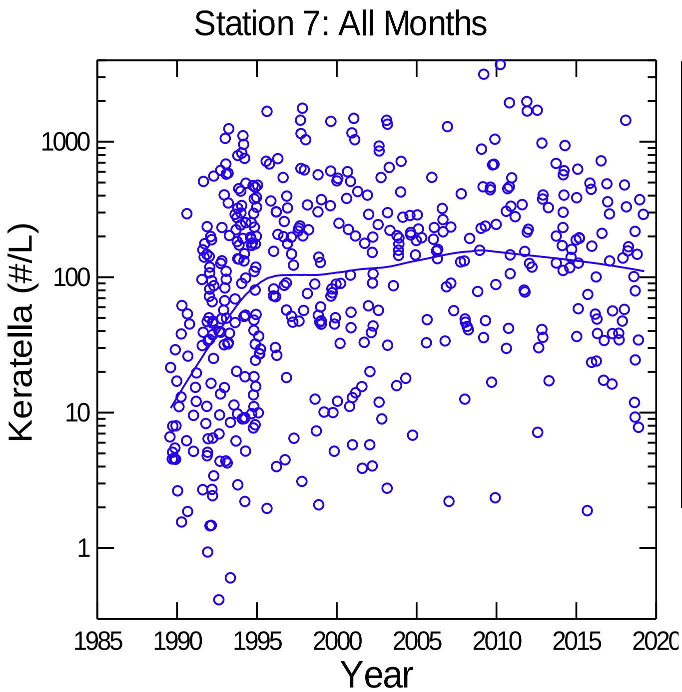
In the cove *Filinia* exhibited a steady increase from 1990 through 2000 rising from about 20/L to nearly 100/L (Figure 132). It has shown a gradual decline in recent years to about 40/L in 2019. When the entire period of record was considered, there is some evidence for a linear increase in the cove despite the recent declines (Table 18).

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



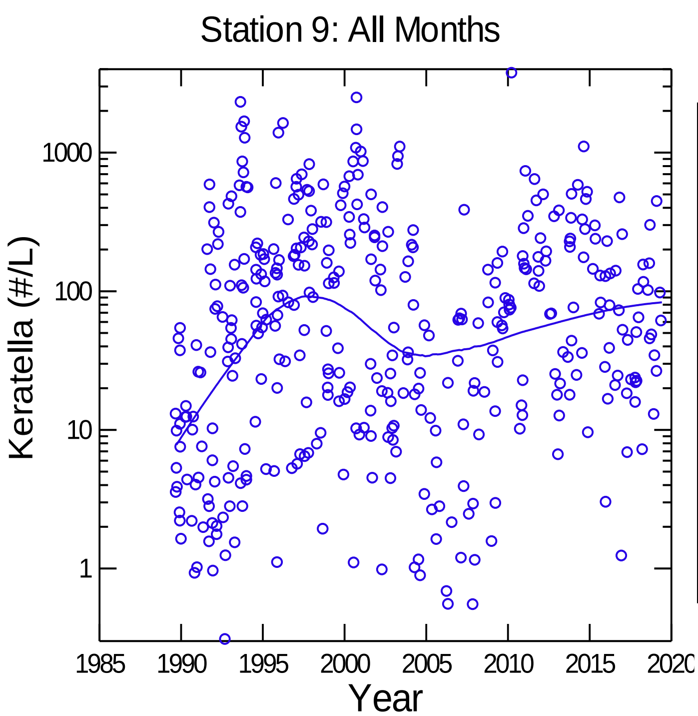
In the river *Filinia* demonstrated an increase through about 2001, declined from 2001-2010 and remained steady since. The trend line indicates about 7/L in 2019, about equal to the 7/L in 1990, but well below the peak of 20/L in 2000 (Figure 133). When the entire period of record was examined, there was a significant negative linear trend (Table 18).

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



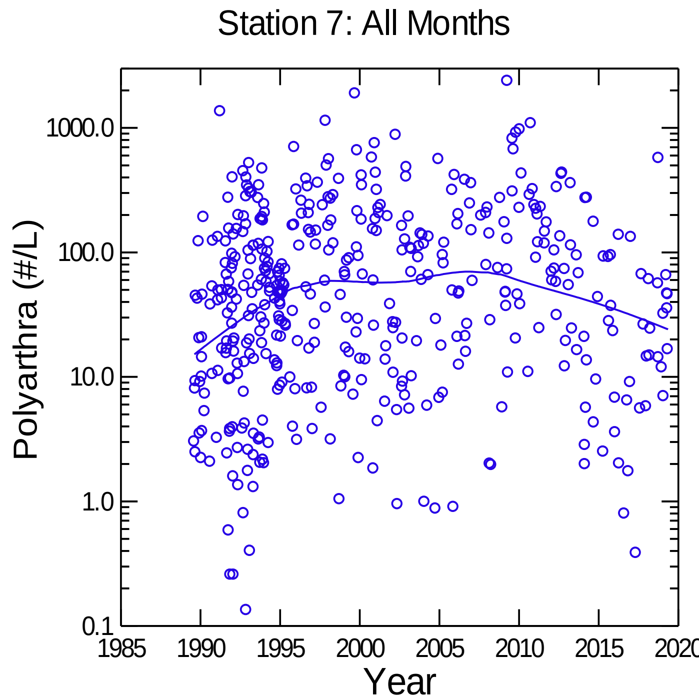
Keratella increased strongly from 1990 to 1995 and has shown a milder increase since then with the trend line approaching 100/L in 2019 (Figure 134). When the entire period of record was examined, there was a significant linear increase (Table 18).

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



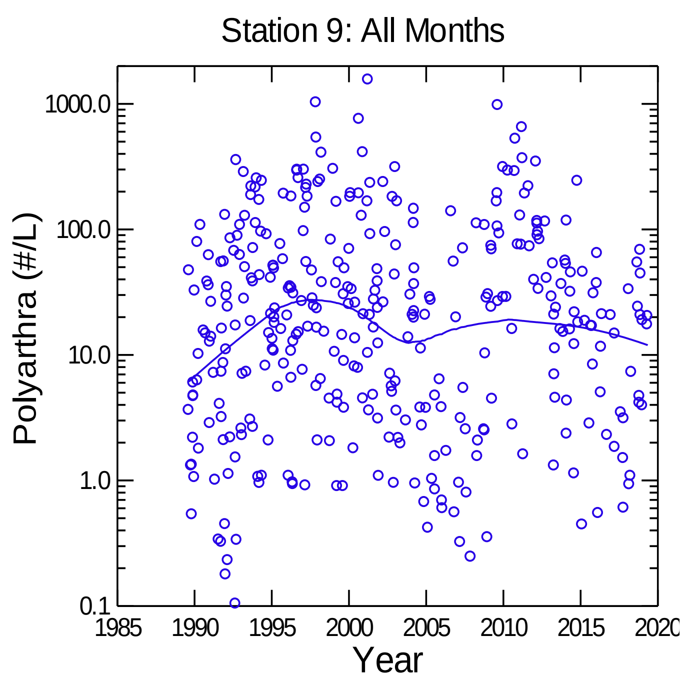
In the river *Keratella* increased from less than 10/L in 1990 to peak values of about 100/L in the mid to late 1990's (Figure 135). The trend line then declined to about 25/L, but since 2005 it has increased reaching about 100/L in 2019. Linear regression showed evidence of a linear increase when the entire study period was considered (Table 18).

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



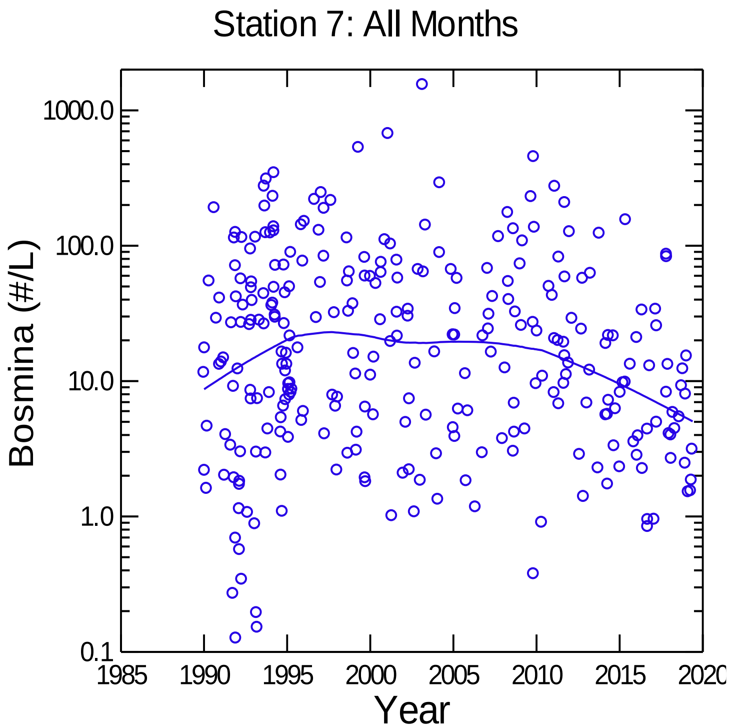
The trend line for *Polyarthra* in the cove increased steadily from 1990 to about 2000 rising from 15/L to about 60/L (Figure 136). Since 2000 densities have increased more slowly and now are dropping again reaching 25/L by 2019. Regression analysis indicated a nearly significant linear increase when the entire period of record was examined (Table 18).

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



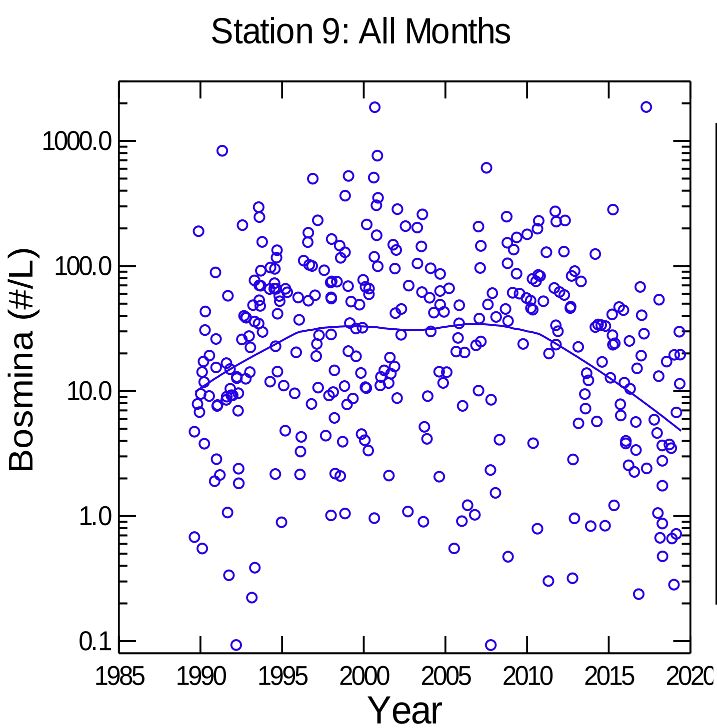
In the river *Polyarthra* showed a marked increase from 1990 to 2000 and then a decline to 2005. By 2019 the trend line approached 10/L (Figure 137). Linear regression analysis did not indicate a significant positive trend over the period of record (Table 18).

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



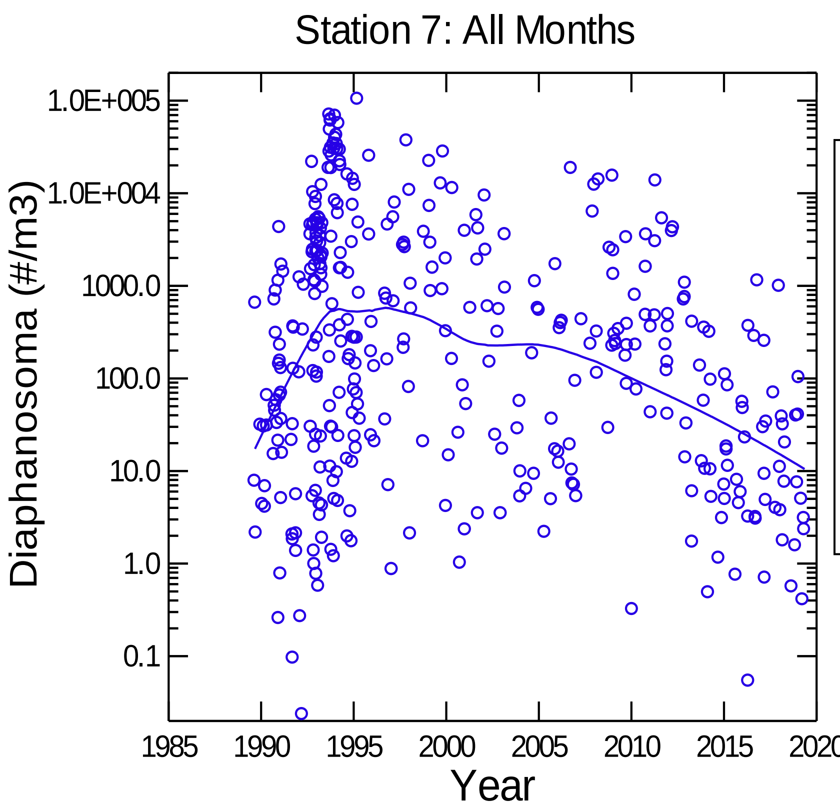
The trend line for *Bosmina* in the cove showed an increase from 8/L in 1990 to about 20/L in 2000 (Figure 138). Since 2000 densities have declined reaching about 5/L in 2019. Linear regression did not indicate a significant trend in the cove over the entire period of record (Table 18).

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



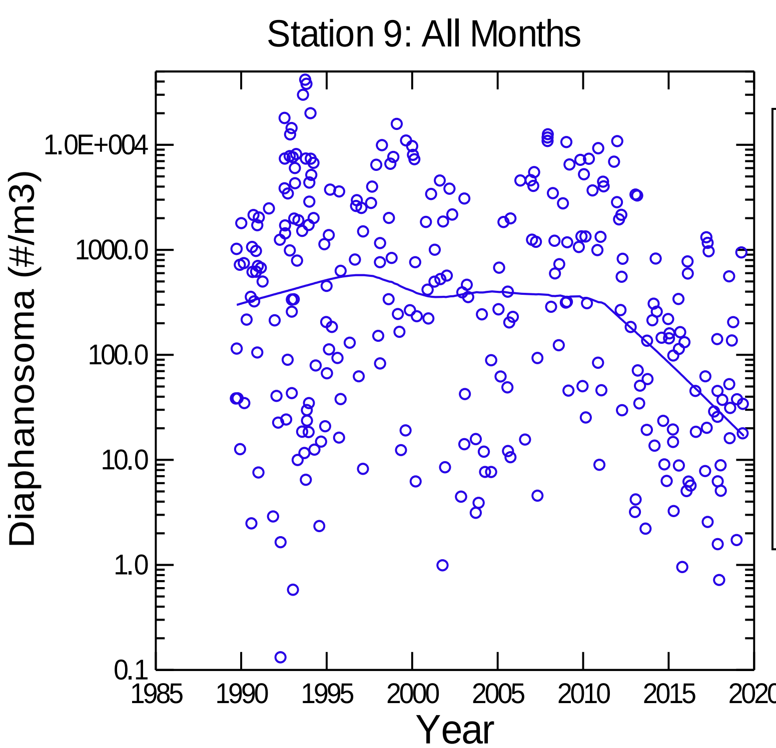
In the river mainstem the LOWESS curve for *Bosmina* increased from 1990 to 1995, and remained rather constant from 1995 to 2010 at about 30/L (Figure 139). Recently, it has declined markedly to about 5/L in 2019. Regression analysis did not indicate a significant linear trend over the entire period of record (Table 18).

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



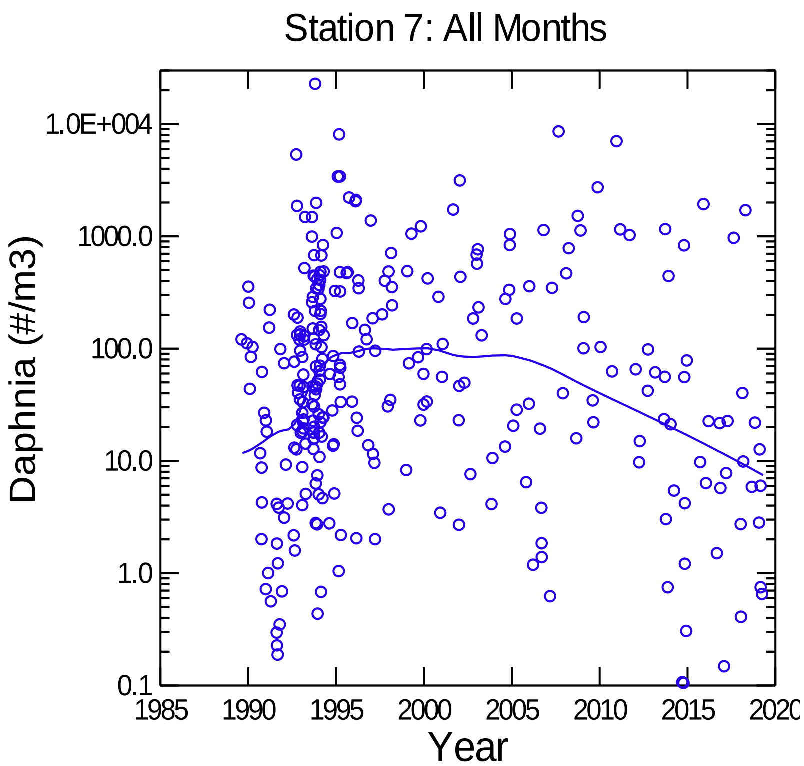
Diaphanosoma increased strongly in the early 1990s from about 12/m^3 nearly 1000/m^3. It gradually declined and by 2019 the trend line was nearing 10/m^3 (Figure 140). Linear regression analysis of the entire period of record indicated a significant decline (Table 18).

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



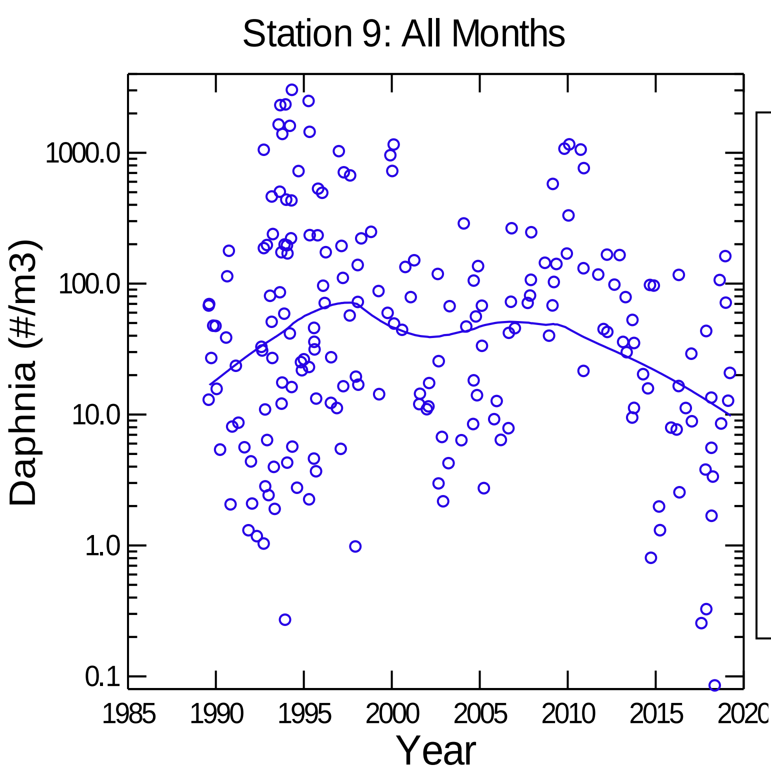
In the river the LOWESS line suggested a generally stable pattern in *Diaphanosoma* until 2010 until a decline set in (Figure 141). The trend line value of 20/m^3 found in 2019 compared with values as high as 600/m^3 in 1999. Regression analysis indicated significant declining trend over the period of record (Table 18).

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



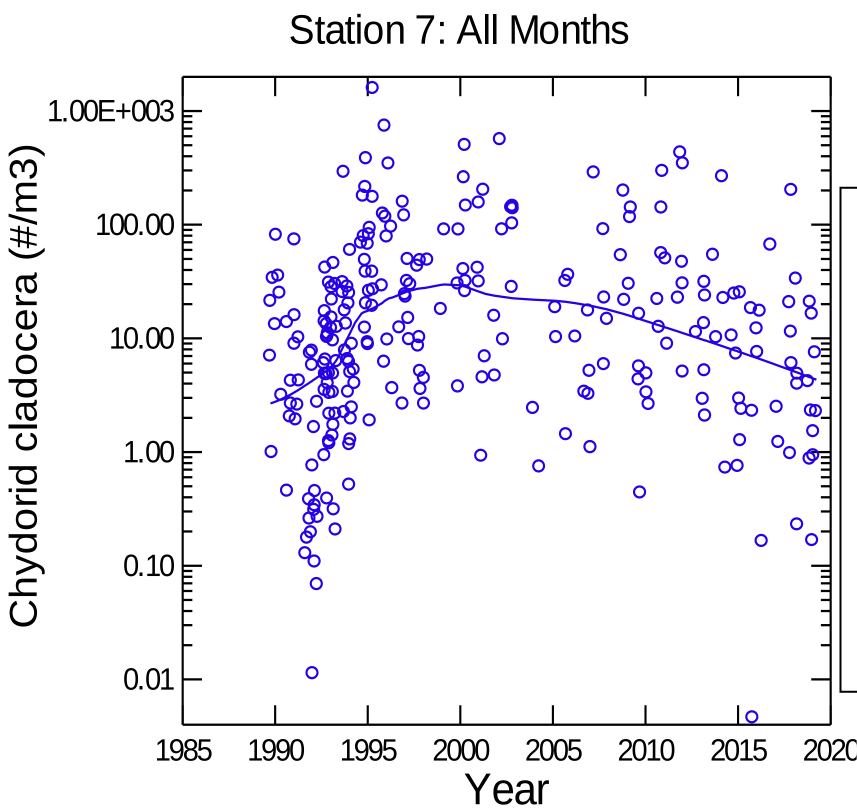
Daphnia in the cove has declined slowly since 1995 from about 100/m^3 to 8/m^3 in 2019 (Figure 142). Regression analysis examining the entire period of record was not significant (Table 18).

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



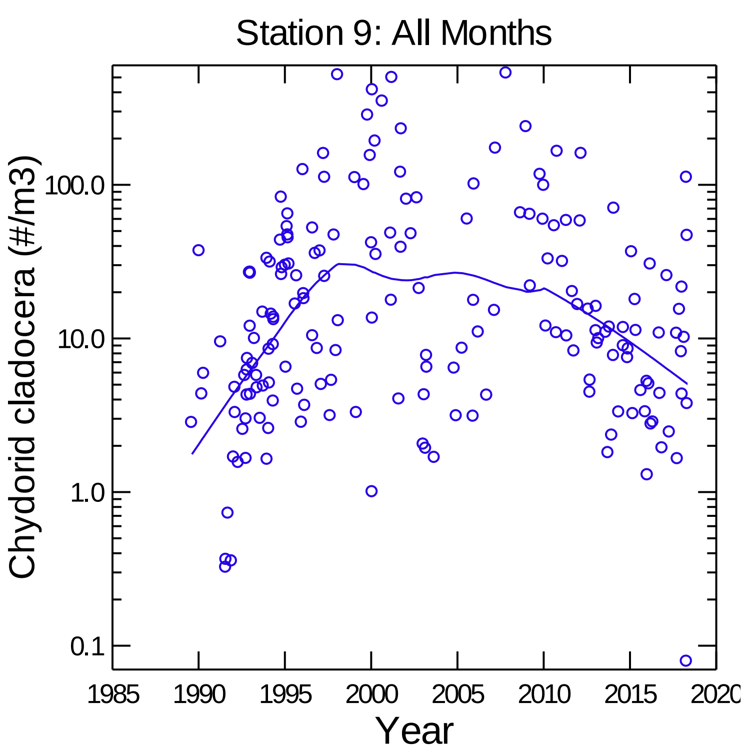
Daphnia in the river increased early on, but has since declined slightly (Figure 143). The trend line in 2019 dropped below 10/m^3, even lower than the level observed at the beginning of the record in 1990. Regression analysis indicated a significant negative trend over the study period (Table 18).

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



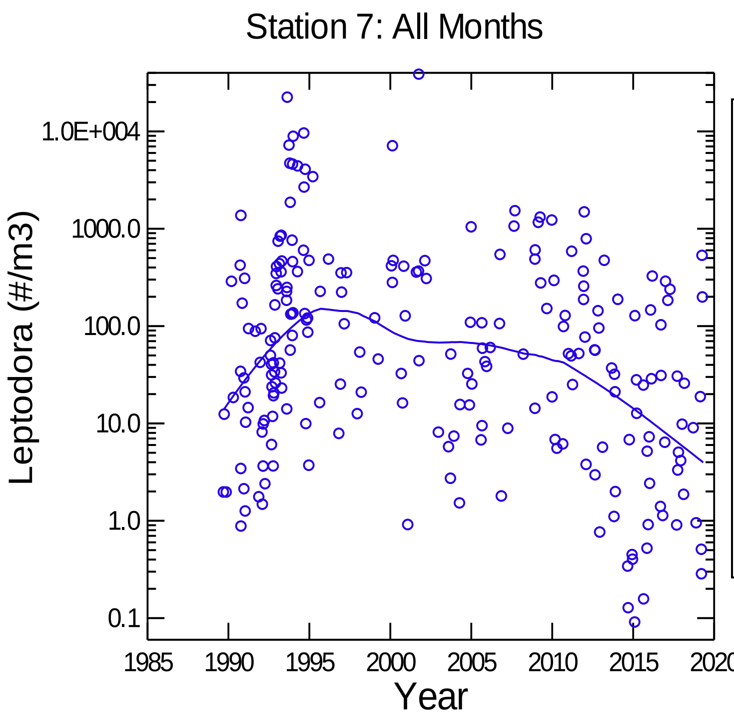
Chydorid cladocera in the cove have increased in the 1990's, but have undergone a slow and consistent decline since that time and 2019 values are those of 1990 (Figure 144). Regression analysis did not show a significant linear temporal trend (Table 18).

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



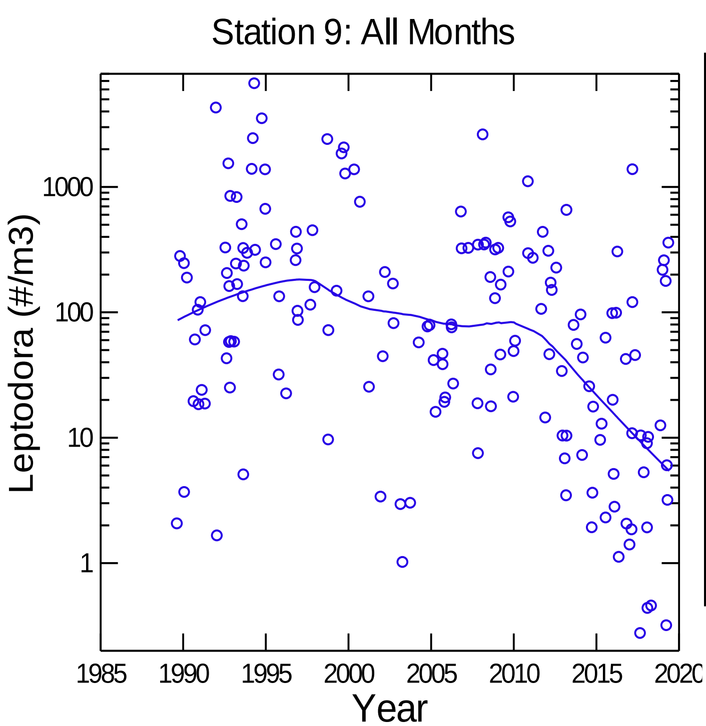
In the river chydorids continued a decrease to about 6/m^3 in 2019, slightly above the low of about 2/m^3 in the early 1990's (Figure 145). There was no evidence for a significant linear trend (Table 18).

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



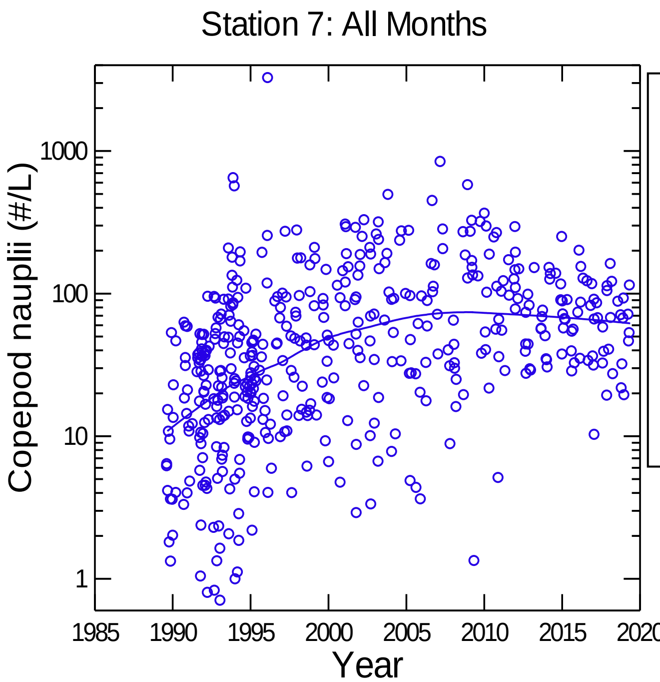
In the cove the trend line for *Leptodora*, the large predaceous cladoceran, has gradually decreased since 1995 and in 2019 reached about 5/m^3, down from its high of about 150/m^3 in 1994 (Figure 146). There was evidence for a significant negative linear trend in *Leptodora* over the entire study period (Table 18).

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



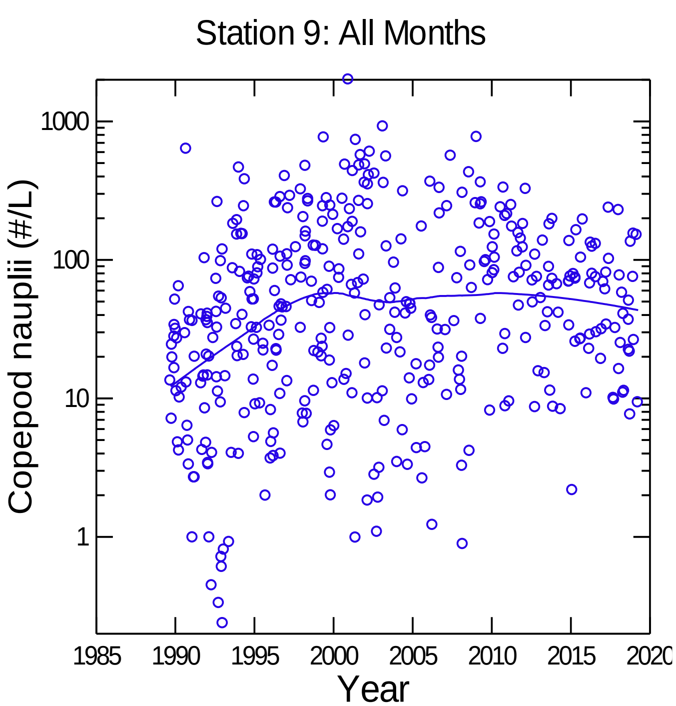
In the river, *Leptodora* densities continued a general decline which began in 1995 resulting in trend line values of about 5/m^3 for 2019 (Figure 147). These values are well below the peak of 200/m^3 in 1994. Interestingly, four data points in 2019 were well above the trend line. Linear regression analysis detected a significant negative linear trend when the whole study period was considered (Table 18).

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



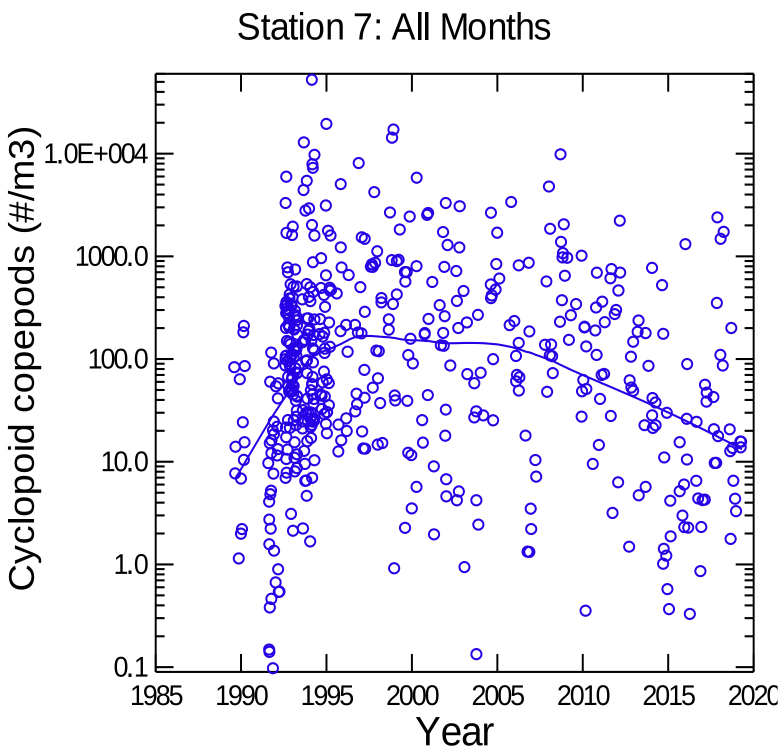
Copepod nauplii, the immature stages of copepods, have shown a positive trend since inception, but it is now leveling at about 70/L as of 2019 (Figure 148). These values are well above the initial values of about 10/L in 1990. A strong linear increase was observed over the study period (Table 18).

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



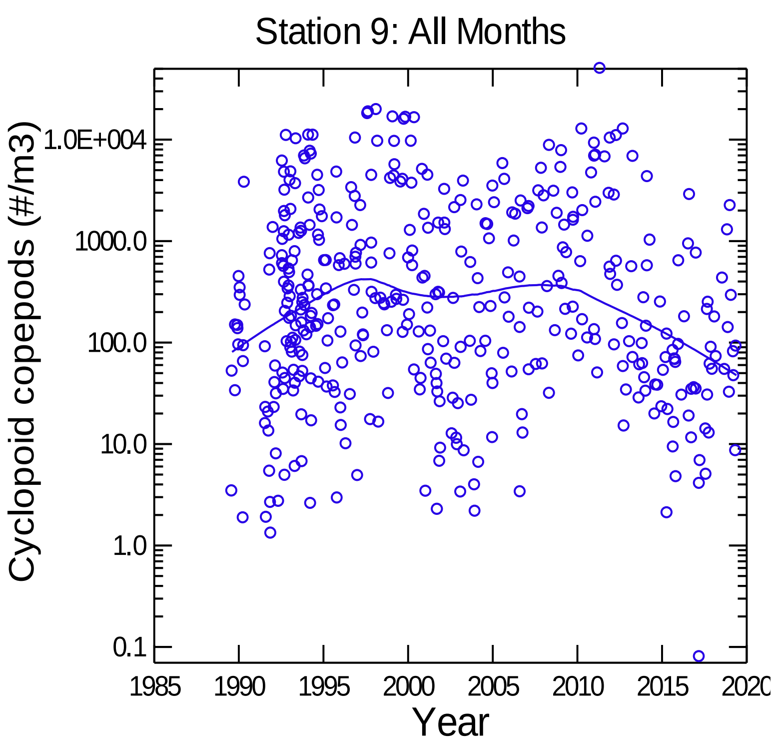
In the river, copepod nauplii showed a a similar leveling of an upward trend (Figure 149). The 2014 LOWESS trend line value was about 40/L, up from an initial value of 10/L in 1990, similar to the previous peak. A significant linear increase was found for nauplii in the river over the study period (Table 18).

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



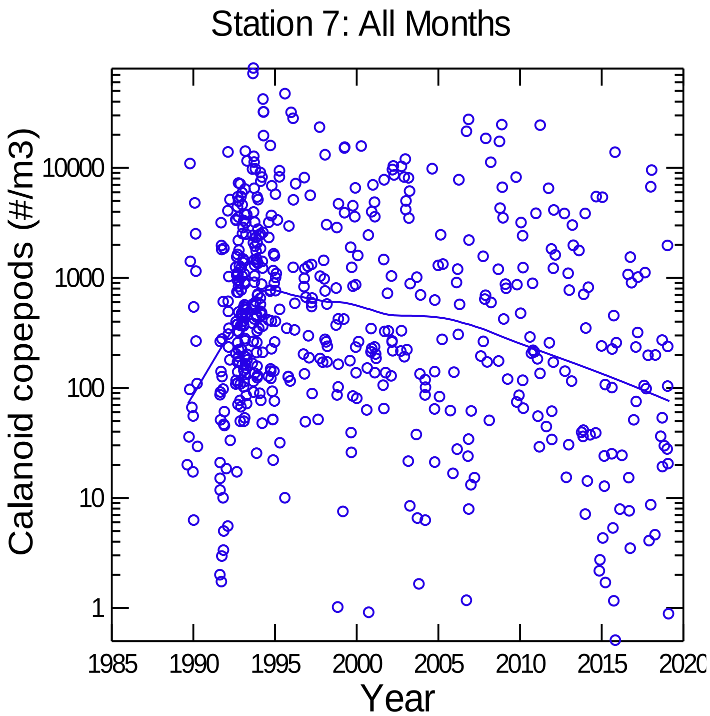
In the cove, cyclopoid copepods increased strongly in the early 1990's, were steady from 1995 to 2005 at about 200/m^3, and since have decreased slowly to about 15/m^3 in 2019 (Figure 150). Cyclopoid copepods exhibited a significant negative linear trend in the cove over the study period (Table 18).

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



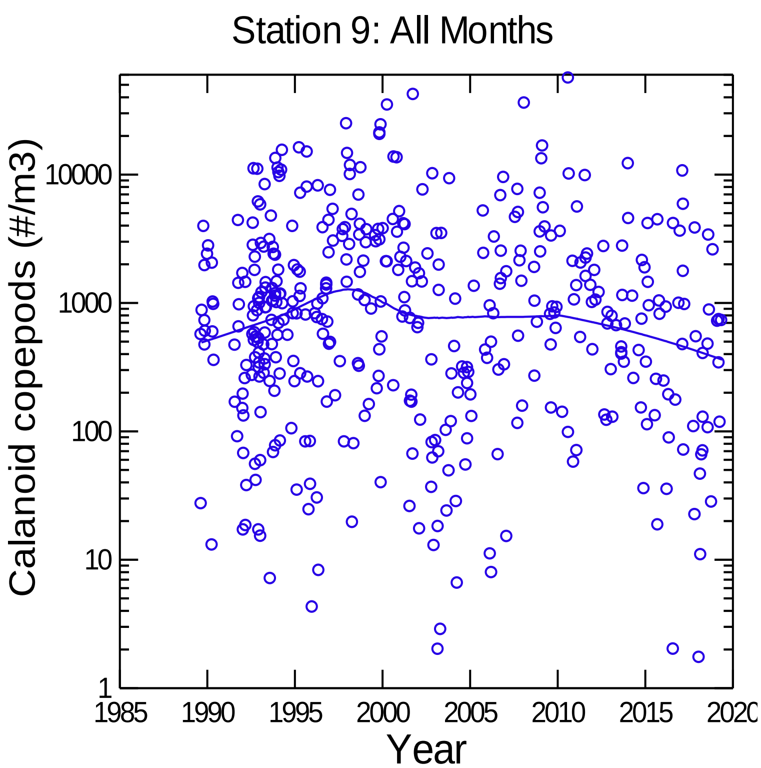
Cyclopoid copepods have shown several cycles over the period (Figure 151). The trend line has varied from 90/m^3 to about 400/m^3. In 2019 cyclopoids were at a low point of about 50/m^3. No linear increase was found when the entire study period was considered (Table 18).

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 80/m^3 in 2019. A significant negative trend was revealed by regression analysis (Table 18).

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 2019 (Figure 153). There was not a statistically significant linear trend (Table 18).

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

E. Ichthyoplankton Trends: 1993-2019

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), and Atherinids (Inland Silversides), all exhibited a spike in density in 1996 followed by a decline in numbers until about 2008. Yellow Perch showed a similar peak in 1996 and has not been a dominant species since. The declines in Clupeid larvae were followed by increases starting in 2010 (Figure 154; Table 19). Especially 2010-2012 showed very high density of these larvae, while numbers decreased again from 2013-2016. There may be an increasing trend again with a small increase in 2017 and a slightly larger increase in 2019. 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.

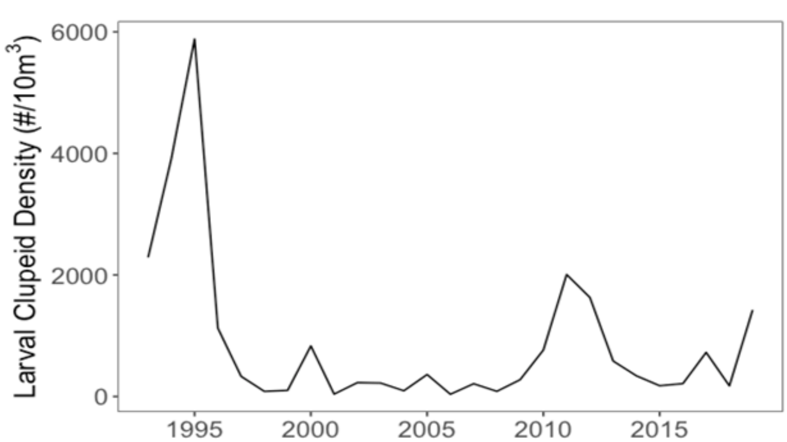
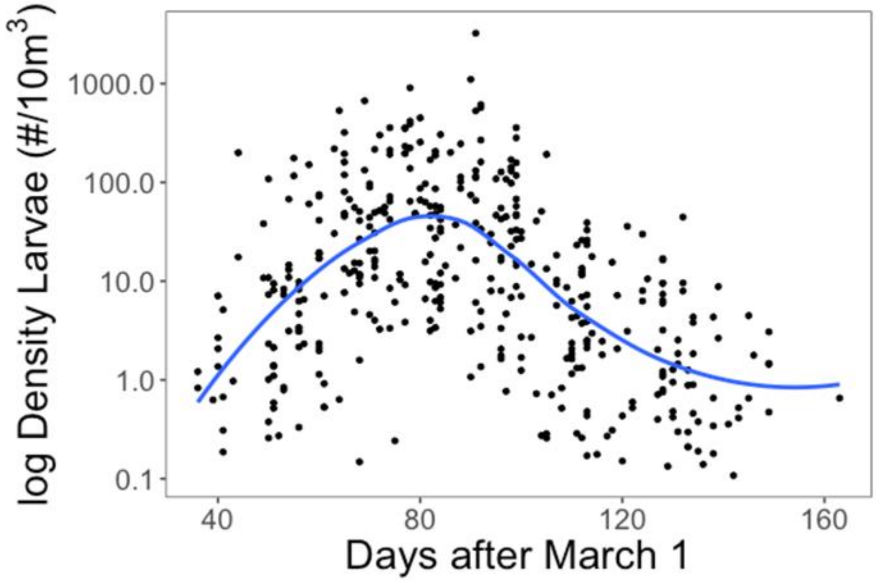


Figure 154. Long-term trend in Clupeid Larvae (*Alosa sp.* and *Dorosoma sp.*; abundance 10 m^{-3}).

Table 19. Density of larval fishes Collected in Gunston Cove and the Potomac mainstem (abundance 10 m^{-3}).

Year	*Alosa* sp.	*Dorosoma* sp.	*Lepomis* sp.	*Morone* sp.	*Perca flavescens*	*Menidia beryllina*
2019	975	365	1	39	0	1
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	4	85	0	61	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 161), 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 157). 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 159).



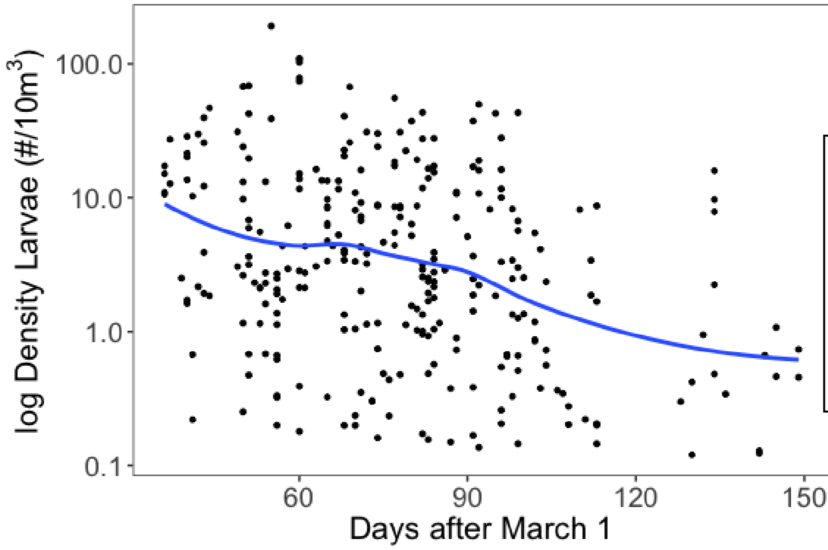
The seasonal pattern in clupeid larvae for 1993-2018 (Figure 155) shows that a peak in density occurs about 80 days after March 1, or mid-May.

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.

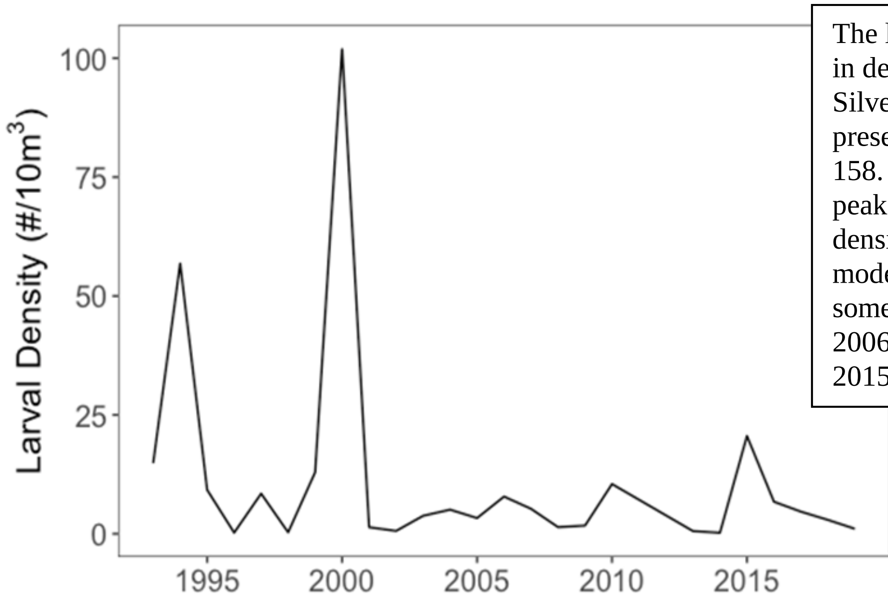
The trend in number of White Perch and Striped Bass larvae per 10 m^3 since 1993 is depicted in the graph in Figure 156. Two peaks are observed in 1995 and 2012 with low densities in other years.

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



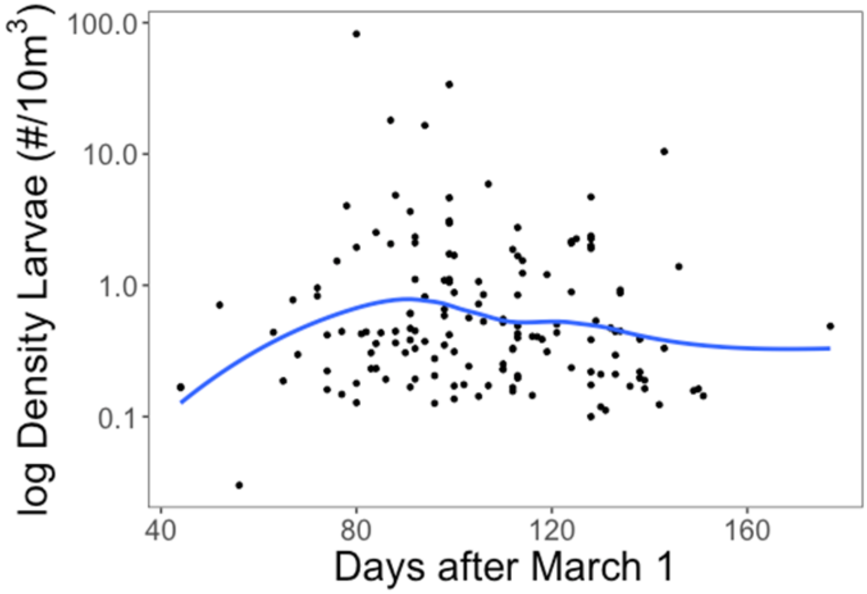
The seasonal density of *Morone* sp. larvae per 10 m^3 is shown in Figure 157. Highest densities are at the start of the sampling season.

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



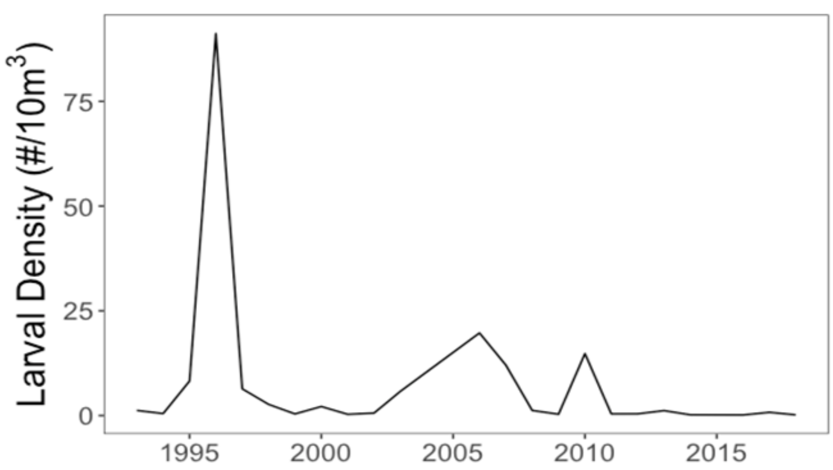
The long-term trend in density of Inland Silverside is presented in Figure 158. After a high peak in 2000, densities have been moderate to low with some small peaks in 2006, 2010, and 2015.

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



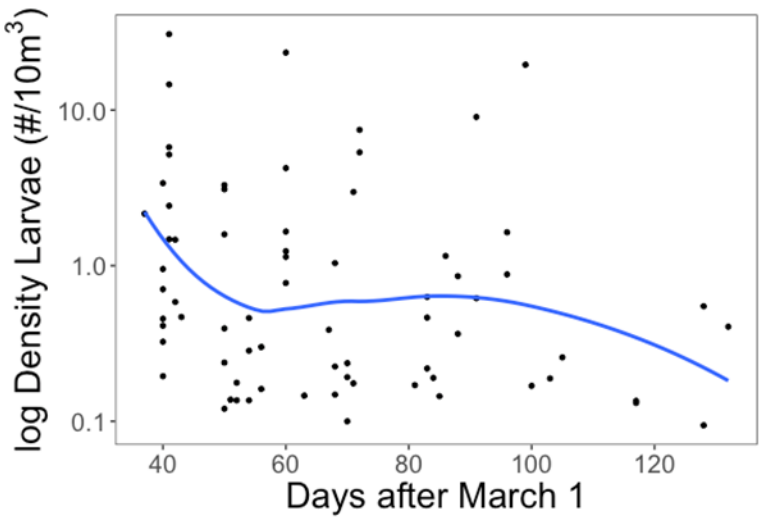
The seasonal occurrence of Inland Silverside per $10m^3$ is shown in a LOWESS graph in Figure 159. The pattern shows maximum density around 90 days after March 1, or around the first week of June.

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: 1984-2019

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 20, 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). On average, catch rates of fishes within the cove are approximately the same over the time of the survey. However, the overall catch rate for the inner cove (stations 7 and 10) in 2019 shows a small peak again, and with higher peaks and shallower troughs since 2006 there may be a slight increasing trend since 2006. 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, 2015 and 2019. Overall, White Perch catches have remained similar and stable over the period of record, while the higher frequency of strong year-classes after 2005 results in an overall small increase in trend starting that time.

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 2019. There was a high peak in catches other than White Perch in 2004, which was primarily due to exceptionally high catches of Blueback Herring (Figures 162, 163).

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 (for all years), 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.

Table 20. Mean catch per trawl of adult and juvenile fishes at Stations 7 and 10 combined. 1984-2019.

Year	All Species	White Perch	Alosa Sp.	Blueback Herring	Alewife	Gizzard Shad	Bay Anchovy	Spottail Shiner	Brown Bullhead	Pumpkin-seed
2019	269.1	141.9	5.0	0.1	0.9	0.0	0.9	104.4	0.1	2.3
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 21. Mean catch per trawl of selected adult and juvenile fishes for all months at Station 9. 1988-2019

Year	All Sp.	Alosa Sp.	Ale-wife	Blueback Herring	White Perch	Bay Anchovy	Spottail Shiner	Brown Blhd	Blue Catfish	Channel Catfish	Tess. Darter
2019	54.7	24.5	11.3	9.6	16.1	0.0	8.9	0.0	1.3	0.0	0.5
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 22. Mean catch per trawl of selected adult and juvenile fishes for all months at Stations 7, 9, and 10 combined. 1984-2019.

Year	All Sp.	White Perch	Alosa Sp.	Blueback Herring	Ale-wife	Gizzard Shad	Bay Anchovy	Spottail Shiner	Brown Blhd	Blue Catfish	Chan Catfish
2019	179.8	89.5	13.1	4.1	5.2	0.0	0.5	64.6	0.1	0.6	0.0
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 23. 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
2019	10	0	0	1	2	2	0	0	0	0	0	0
2019	7	0	0	1	1	2	2	2	1	0	0	0
2019	9	0	0	1	2	2	2	2	1	0	0	0
2018	10	0	0	1	2	2	2	1	1	0	0	0
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
2017	10	0	0	1	2	0	0	0	0	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
2016	10	0	0	1	2	1	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
2015	10	0	0	1	2	0	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
2014	10	0	0	1	2	2	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
2013	10	0	0	1	2	2	1	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
2012	10	0	0	1	2	2	0	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
2011	10	0	0	1	2	3	2	0	1	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
2010	10	0	0	1	1	2	2	0	0	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
2009	10	0	0	1	2	2	2	3	1	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
2008	10	0	0	1	2	2	2	2	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
2007	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

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

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

Table 24. Mean catch per trawl of adult and juvenile fishes in all months at each station.

Year	7	9	10
2019	356.2	54.7	112.4
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

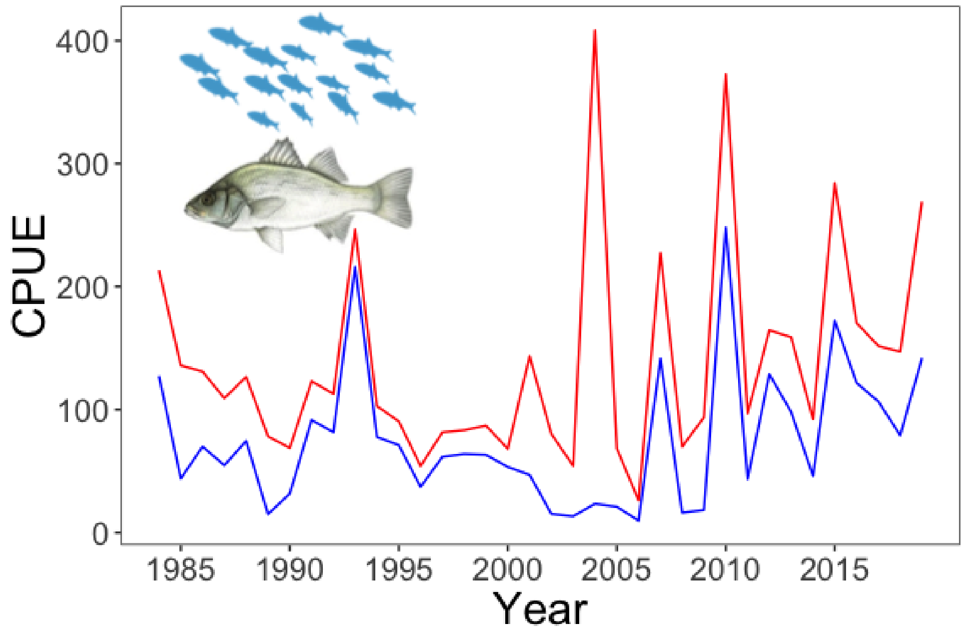


Figure 162. Trawls. Annual Averages. All Species (red) and *Morone americana* (blue). Cove Stations 7 and 10. 1984-2019.

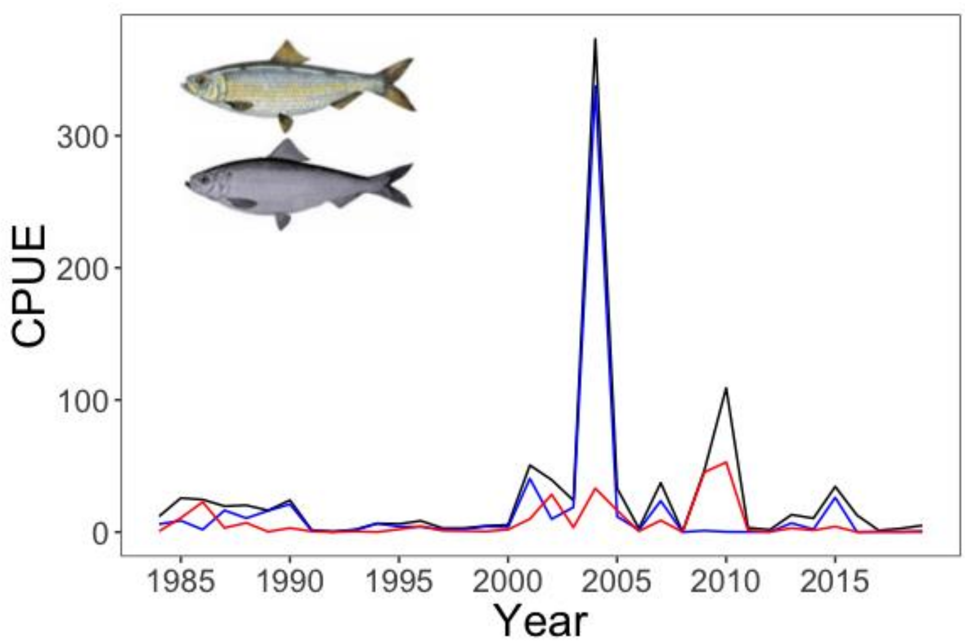


Figure 163. Trawls. Annual Averages. *Alosa aestivalis* (blue), *Alosa pseudoharengus* (red), and all combined *Alosa sp.* (black). Cove Stations 7 and 10.

Gizzard Shad catch rates in trawls in 2019 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 2019 were low like they were in the last four 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.

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, 2015, and 2018 (Figure 165). We collected an unprecedented high number of Spottail Shiner specimens in 2019. These individuals were mostly juveniles, indicating relatively high reproductive success as measured by this survey. The trends for sunfishes showed a similar pattern of higher abundance since 2005 than before. 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.

Two Brown Bullhead specimens were captured in cove trawls in 2019, fitting the trend of continuing decline that has proceeded continuously since the start of the survey (Figure 166). Tessellated Darter was collected in moderately high numbers in trawl samples. The highest peak in abundance since the start of collections was seen in 2018. There are 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). 2019 abundances are similar again to those in 2014.

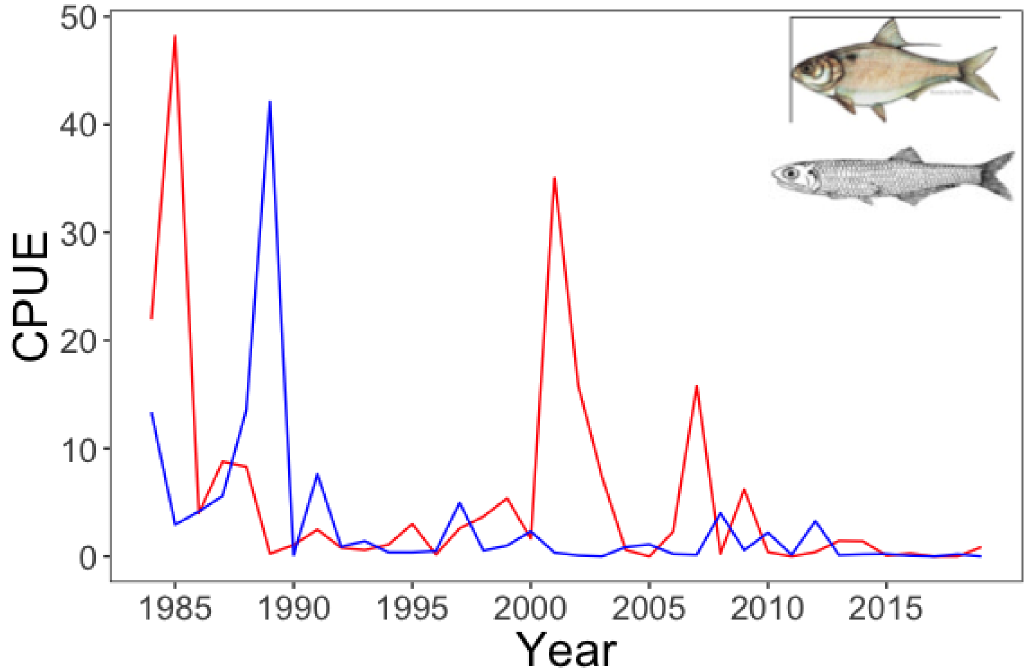


Figure 164. Trawls. Annual Averages. Cove Stations 7 and 10. *Dorosoma cepedianum* (blue) and *Anchoa mitchilli* (red).

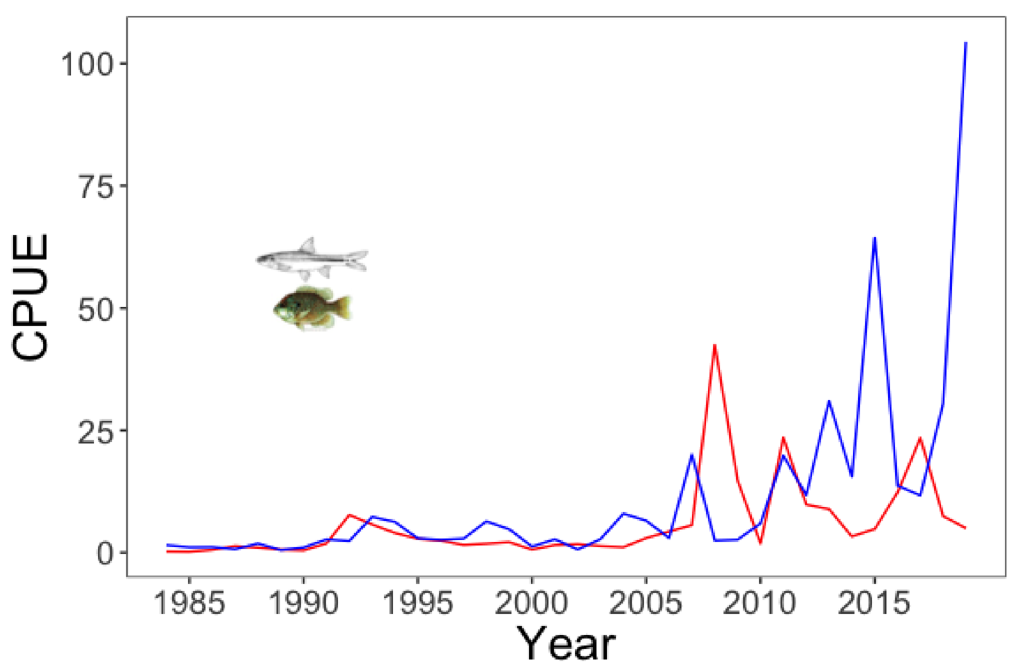


Figure 165. Trawls. Annual Averages. *Notropis hudsonius* (blue) and all *Lepomis sp.* (red). Cove Stations 7 and 10.

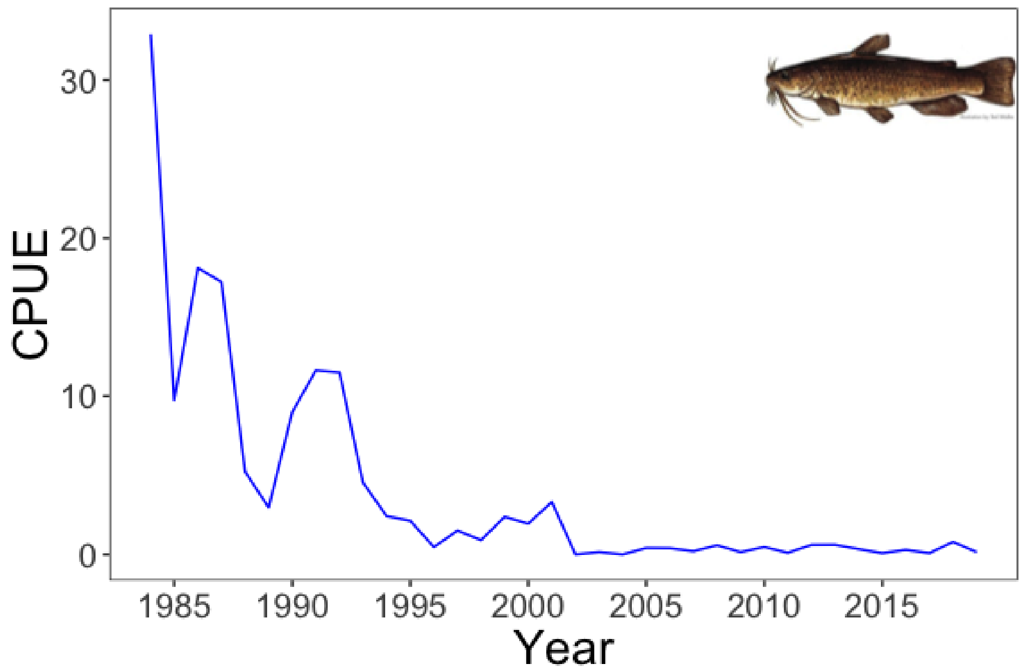


Figure 166. Annual Averages. *Ameiurus nebulosus*. Cove Stations 7 and 10.

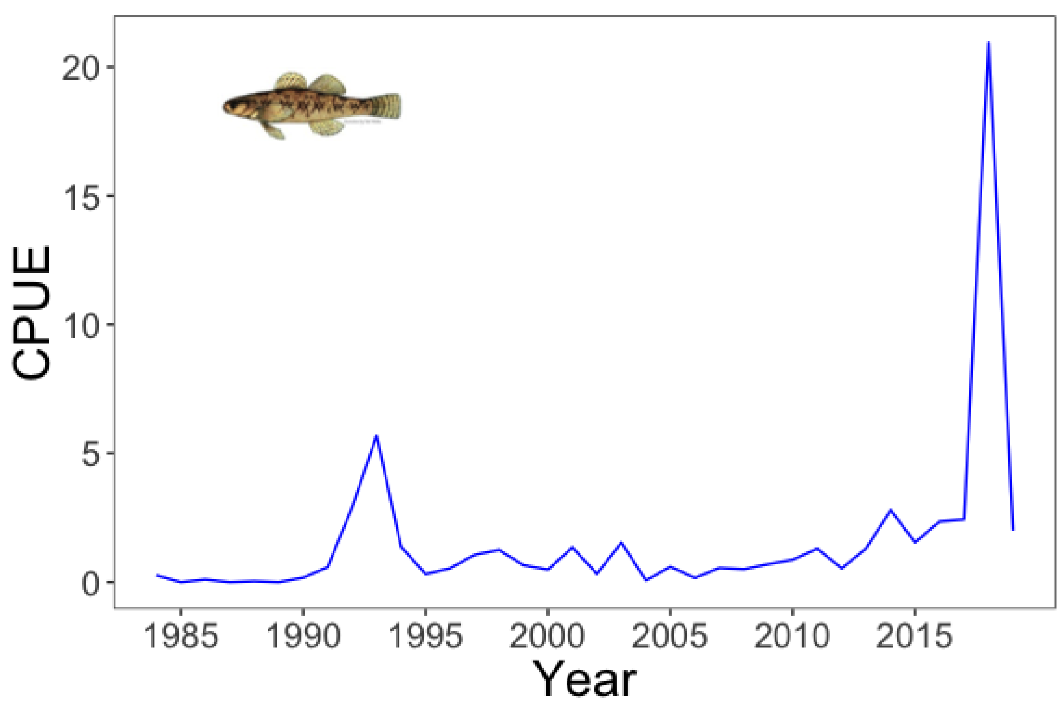


Figure 167. Trawls. Annual Averages of *Etheostoma olmstedi*. Cove stations 7 and 10.

Mean catch at station 9 in 2019 was up again from low abundances since 2013, and was right at the long-term mean of 54 (Table 19, Figure 168). The increase in catch in 2019 deviated from the catch of white Perch, which went slightly down. The high abundance in 2019 was due to the increase in catch of Spottail Shiner and Alosines. The slight increase in 2018 was due to an increase in Blue Catfish catch, but Blue Catfish did not contribute much to the high total abundance in 2019. 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, 2018 and 2019. The mean catch of all trawl stations combined in 2019 was up again from last year and higher than the long-term mean of 103 (Table 20). 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.

At the river channel station (station 9), catches in 2019 were slightly higher than the last six years (Figure 168). As in the inner cove, much of the variation at station 9 is directly attributable to the catch of White Perch. In 2019, increases in Spottail Shiner and Alosines catches was responsible for the increase in total catch (Figure 168, 169). The increase in Alosines is a good sign, and may be the result of a moratorium on catching these species since 2012.

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, which saw an uptick in 2019, while American Eel has remained rare since 1994.

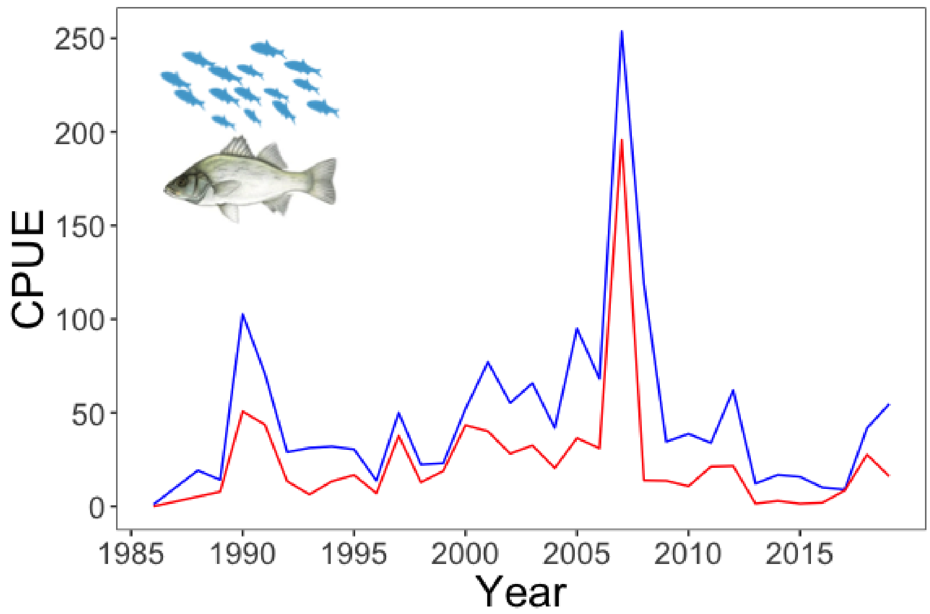


Figure 168. Trawls. Annual averages. River Station (9). Total catch (blue) and *Morone americana* (red).

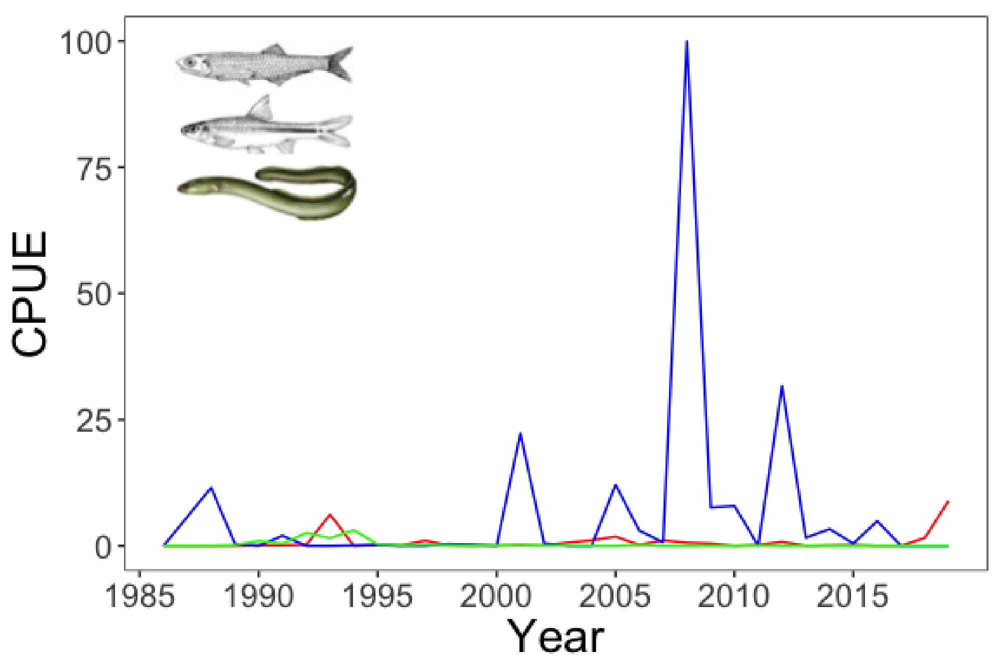


Figure 169. Trawls. Annual Averages. River Station (9). *Anchoa mitchilli* (Blue), *Notropis hudsonius* (red), and *Anguilla rostrata* (green).

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. No native bullheads were collected at Station 9 in 2019, and 13 Blue catfishes were collected. The invasive Blue Catfish 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.

Station 9 generally represents low catch rates for the demersal species Tessellated Darter and Hogchoker (Figure 171). In 2018 however, while not unprecedented as in the cove, the mainstem saw a peak in Tessellated Darter abundance. Less were collected in 2019, but abundances were still above average for recent years. No Hogchokers were collected in 2019, which is same as last year.

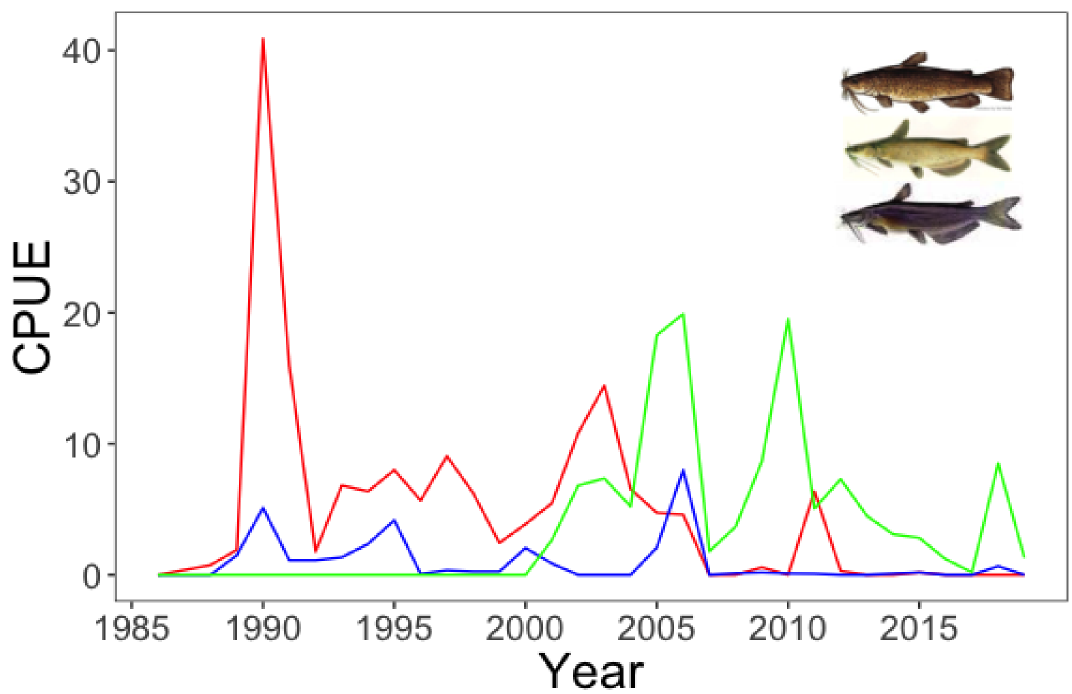


Figure 170. Trawls. Annual Averages. River Station (9). *Ameiurus nebulosus* (blue), *Ictalurus punctatus* (red), and *Ictalurus furcatus* (green).

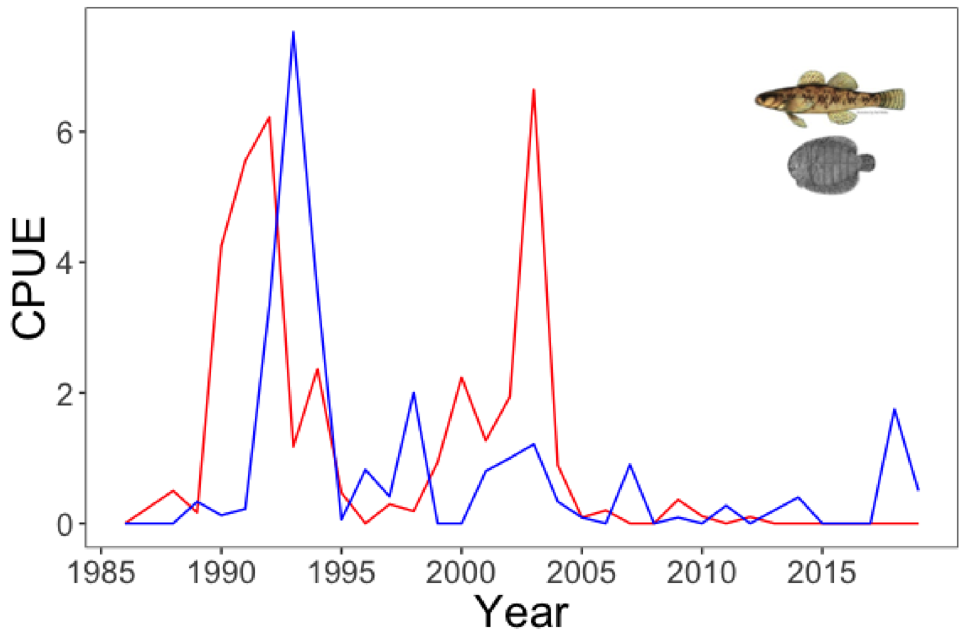


Figure 171. Trawls. Annual Averages. *Etheostoma olmstedi* (blue) and *Trinectes maculatus* (red). River Station (9).

Seine nets

Overall Patterns

The long-term trend of seine catches shows a stable pattern of catches amidst inter-annual variability (Table 23, 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 23). The number of seine tows over the period of record is shown in Table 24.

Table 25. Mean Catch per Seine of Selected Adult and Juvenile Fishes at all Stations and all Months. 1985-2019.

Year	All Species	White Perch	Banded Killifish	Blueback Herring	Alewife	All *Alosa* Sp	Spottail Shiner	Inland Silverside
2019	112.6	15.4	42.6	0.0	0.6	28.3	1.3	4.9
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 26. The number of seines in each month at Station 4, 4B, 6, and 11 in each year. 1985-2019.

Year	Station	1	2	3	4	5	6	7	8	9	10	11	12
2019	4	0	0	0	1	2	2	2	0	0	0	0	0
2019	6	0	0	0	1	2	2	2	2	1	0	0	0
2019	11	0	0	0	1	2	2	2	2	1	0	0	0
2019	4B	0	0	0	1	2	2	2	2	1	0	0	0
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

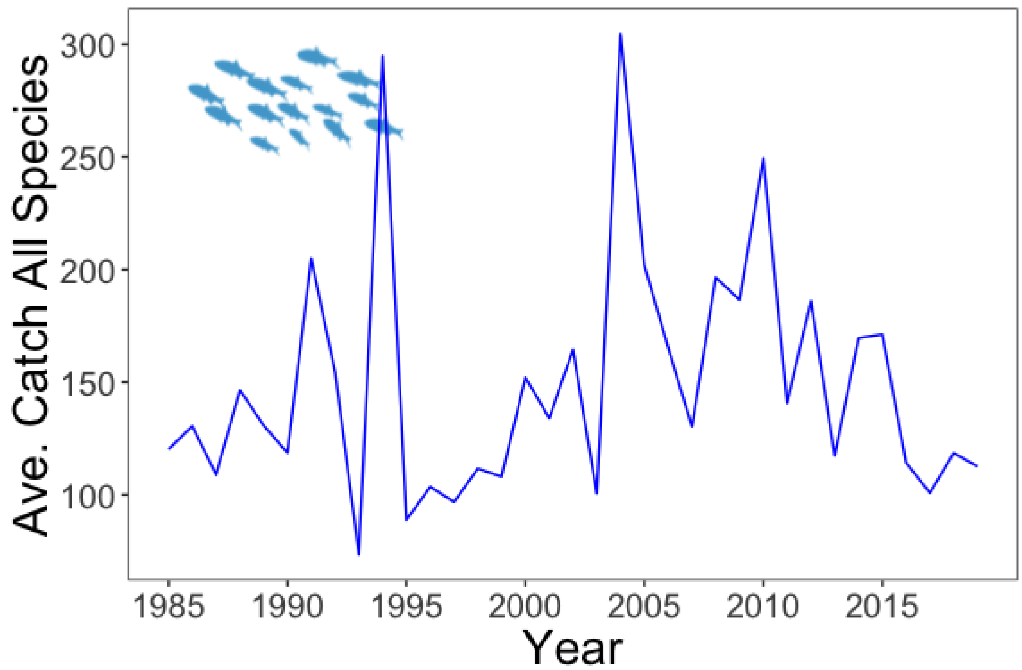


Figure 172. Seines. Annual Average over Stations 4, 4A, 6, and 11. All Species. 1985-2019.

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 (Figures 173, 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.

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, creating habitat for other species than White Perch, which is a pelagic species. 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.

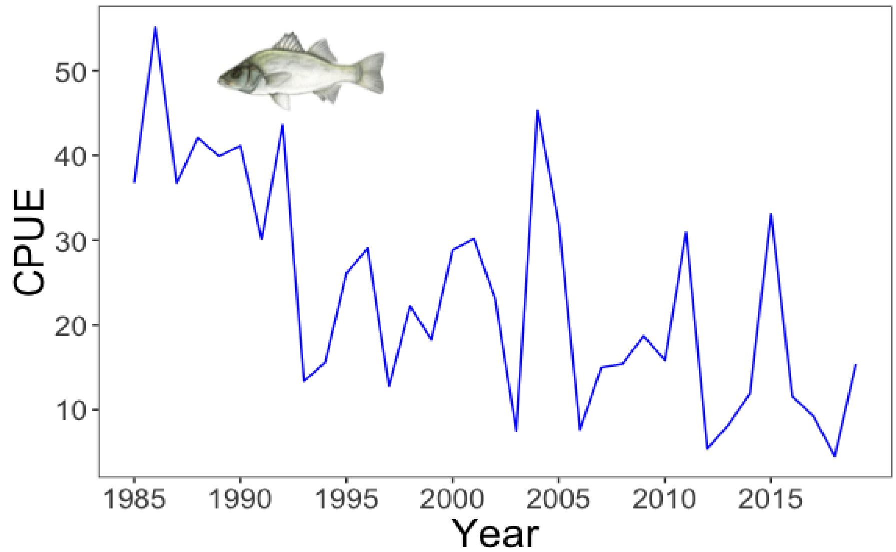


Figure 173. Seines. Annual Average Stations 4, 4A, 6, and 11. *Morone americana*. 1985-2019.

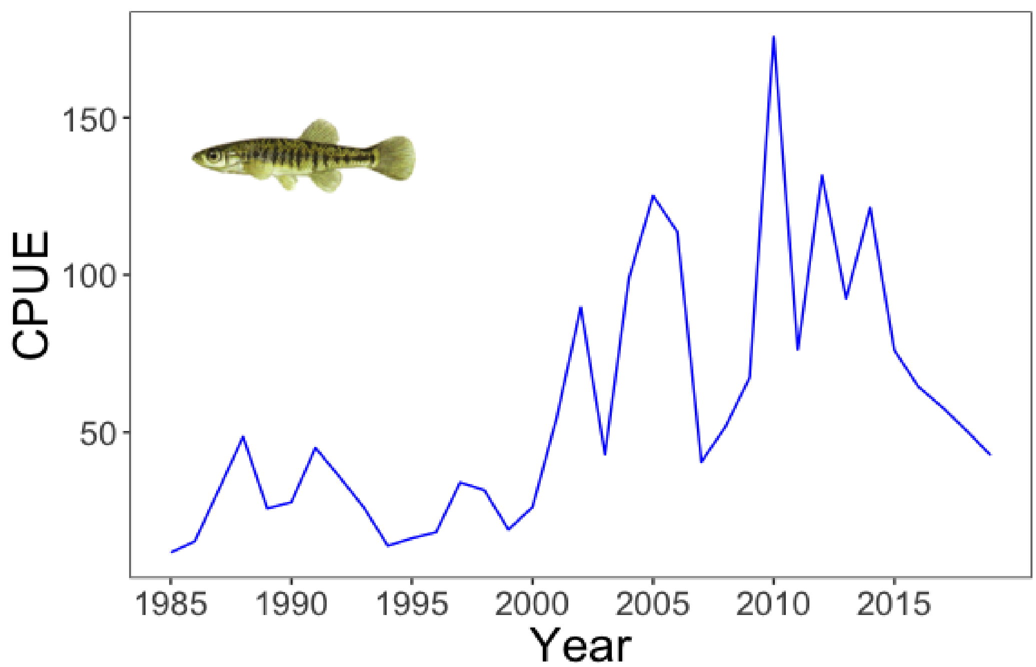


Figure 174. Seines. Annual Average Stations 4, 4A, 6, and 11. *Fundulus diaphanus*. 1985-2019.

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, 2018 and now in 2019. 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 (described in the 2018 Anadromous Report).

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 in seine collections.

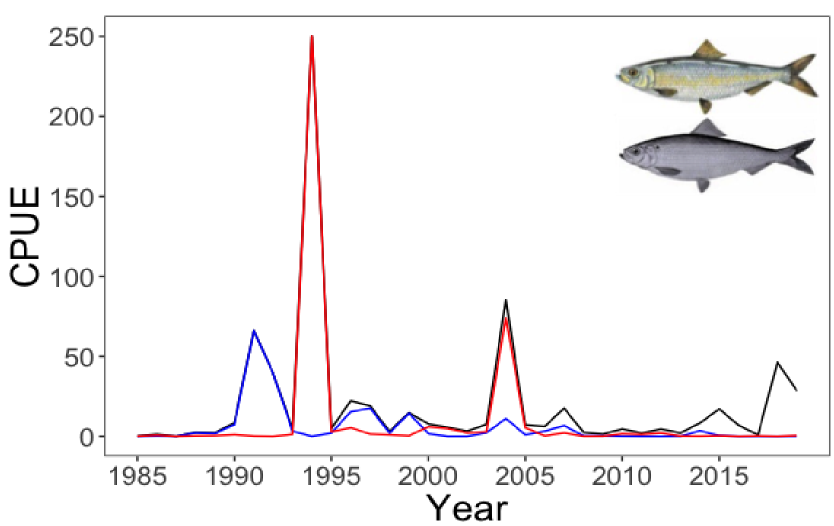


Figure 175. Seines. Annual Average over 4, 4A, 6, and 11 Stations. *Alosa aestivalis* (blue), *A. pseudoharengus* (red), and all *Alosa sp.* (black; *A. aestivalis*, *A. pseudoharengus*, *A. mediocris*, *A. sapidissima*, and unidentified Herring and Shad species). 1985-2019.

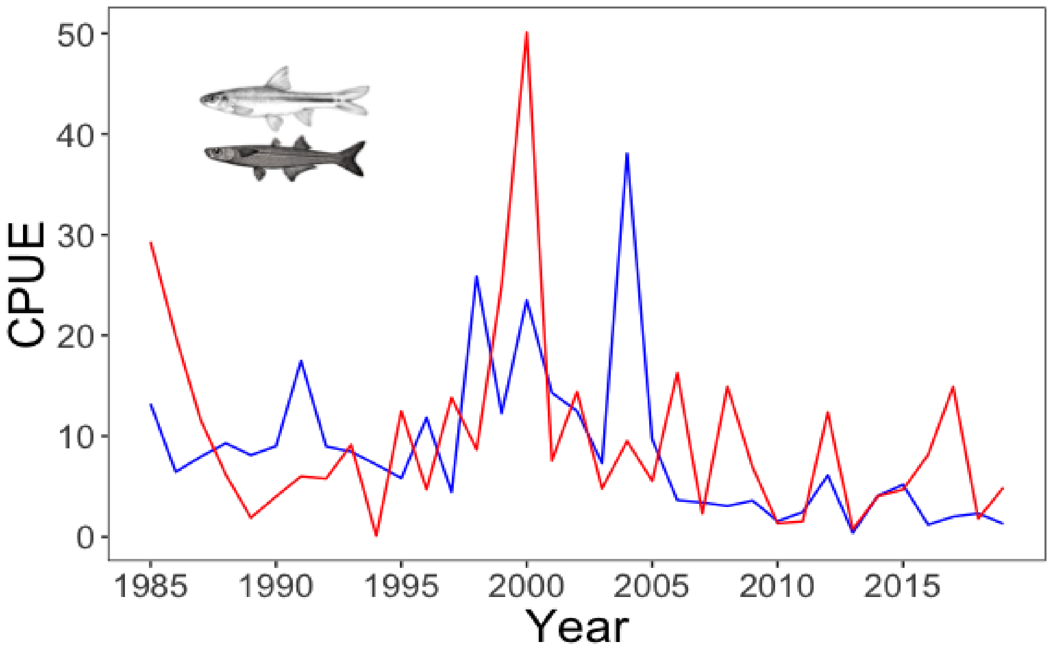


Figure 176. Seines. Annual Average over 4, 4A, 6, and 11 Stations. *Notropis hudsonius* (blue) and *Menidia beryllina* (red). 1985-2019.

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). After very high abundance of sunfishes in the fyke nets in the first year (2012), the fyke net collections have seen moderate abundances evenly distributed over species that prefer SAV beds as habitat (Table 25, Figure 177). 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). A species consistently sampled at moderately high levels with the fyke nets is Banded Killifish, which benefits from extensive SAV beds as habitat (Figure 179). 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. The number of sampling days per month where both fyke nets were set is shown in Table 28.

Low catches of Spottail Shiner and Inland Silverside were found in the fyke nets in 2019. Only 2017 saw a high catch of Inland Silverside. With the variable record within the SAV-beds as represented by the fyke net 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.

After 2018 yielded in the lowest abundance in fyke nets for the period of record, catches were up to normal levels again in 2019 (Table 27, Figure 177). This seems directly related to SAV cover, which was close to absent in 2018, but present in all other years since the period of record (2012-2019). Collections were dominated by sunfishes again in 2019, which is the species that is mostly represented with the fyke net collections. Like previous years, the relative contribution of species in fyke nets is different than collected with trawl or seine nets. The fyke nets mainly represents SAV-associated species such as several species of sunfishes. When the catch is low this seems associated with low SAV cover, since 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), but also species associated with open water, such as White Perch (Figure 178).

Table 27. Mean Catch per Fyke of Selected Adult and Juvenile Fishes at all Stations and all Months. 2012-2019.

Year	All Species	Sunfish	Banded Killifish	Inland Silverside	Tesselated Darter	Brown Bullhead	Largemouth Bass	Goldfish
2019	48.3	30.3	13.9	0.4	0.7	0.0	0.1	0.4
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

Table 28. The number of fykes in each month at Station Fyke 1 and Fyke 2 in each year. 2012-2019.

Year	Station	4	5	6	7	8	9
2019	Fyke1	0	2	2	2	2	1
2019	Fyke2	0	2	2	2	2	1
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

Other species that are collected with the fyke nets include native catfishes, such as the Brown Bullhead (Figure 181). They are generally collected in low abundances with the fyke nets as well, and none were collected in 2019. We did see a spike in Brown Bullhead abundance in 2014, signifying that they have not been extirpated by the invasive Blue Catfish. We consistently find low abundances of the invasive Goldfish as well (Figure 182). Largemouth Bass also benefits from extensive SAV cover to better hide for prey species. While it may generally be successful in avoiding our stationary gear, we do generally collect some Largemouth Bass specimens in low abundances.

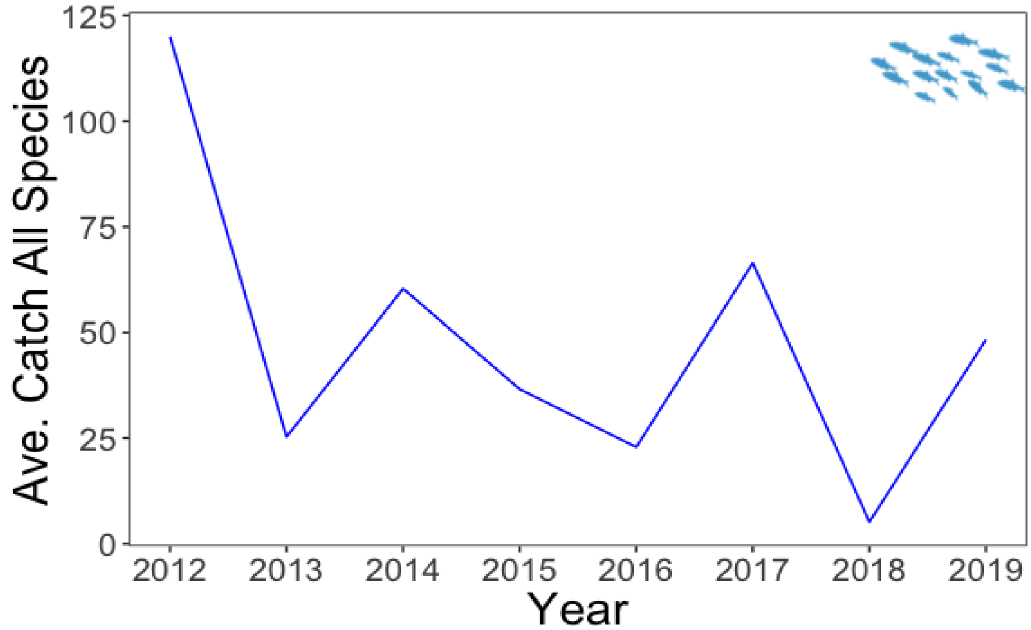


Figure 177. Fykes Annual Average over Stations Fyke 1 and Fyke 2. All Species. 2012-2019.

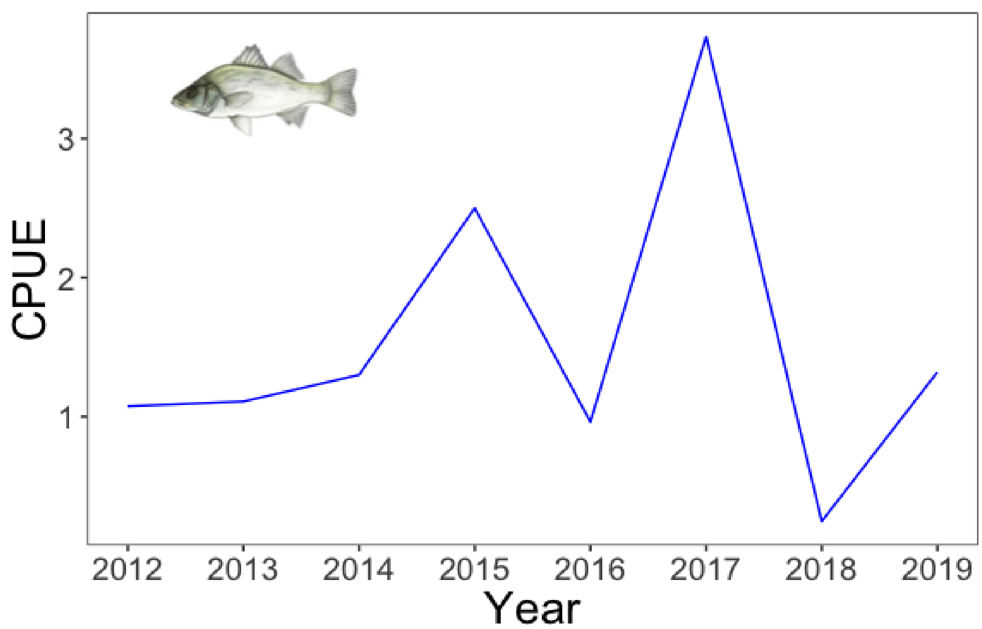


Figure 178. Fyke Annual Average Stations Fyke 1 and Fyke 2. *Morone americana*. 2012-2019.

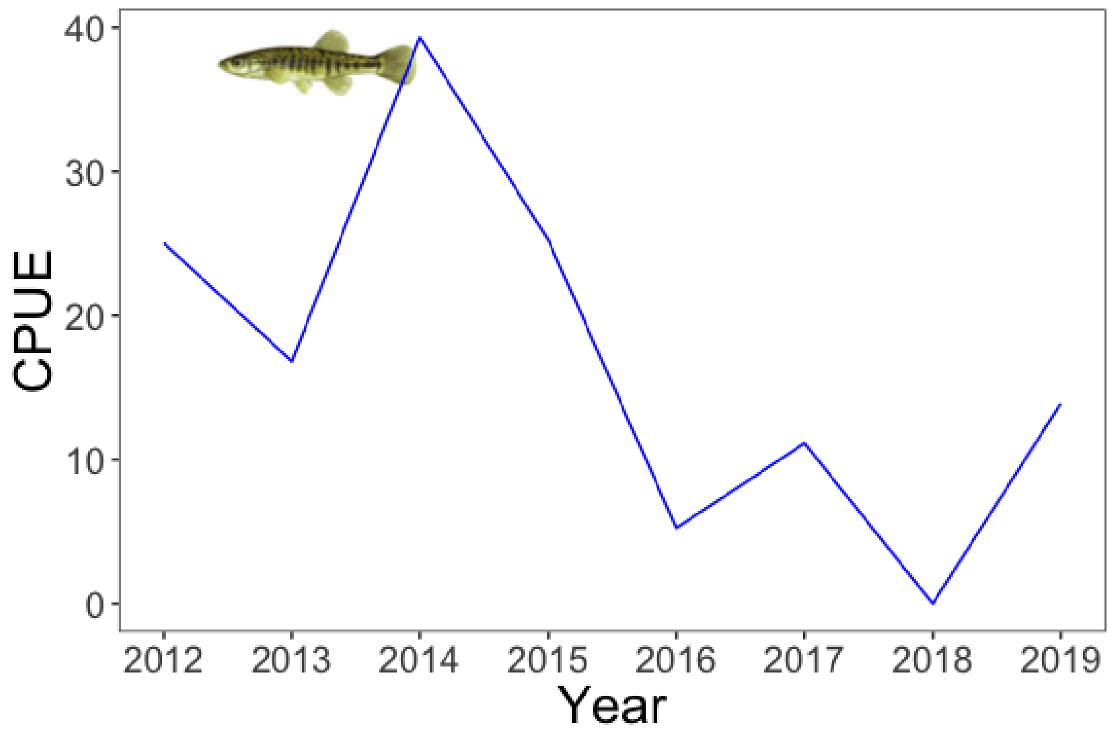


Figure 179. Fyke Annual Average Stations Fyke 1 and Fyke 2. *Fundulus diaphanus*. 2012-2019.

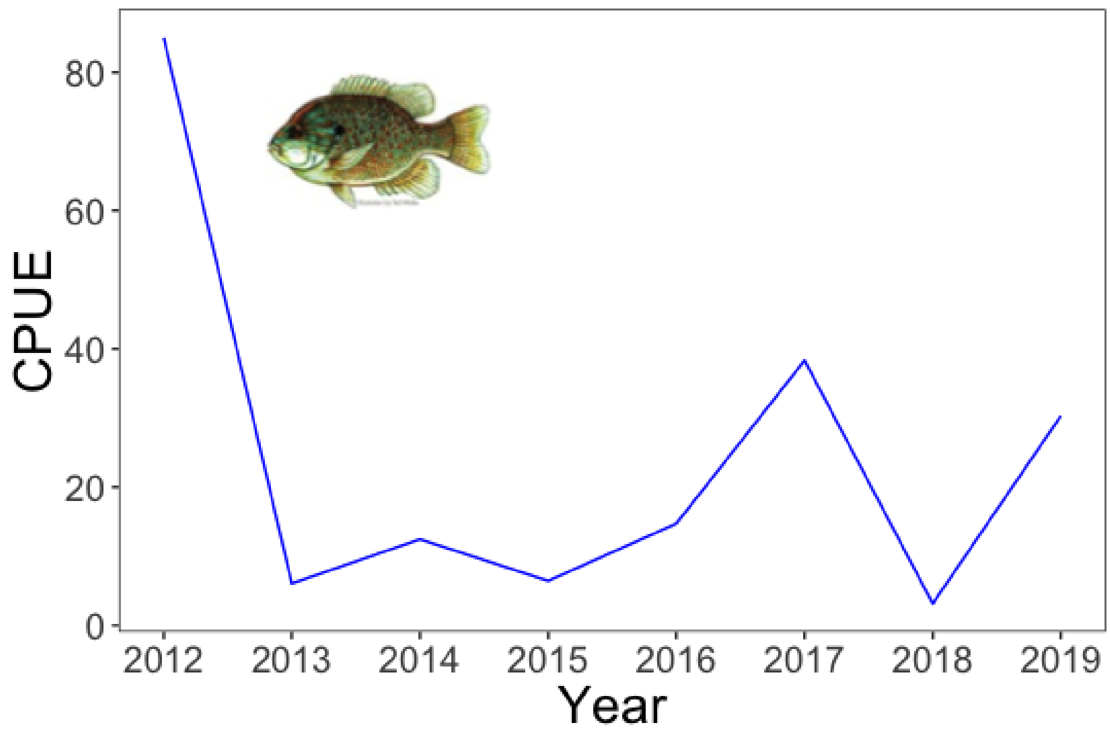


Figure 180. Fykes Annual Average over Fyke 1 and Fyke 2 Stations. All *Lepomis sp.* (blue). 2012-2019.

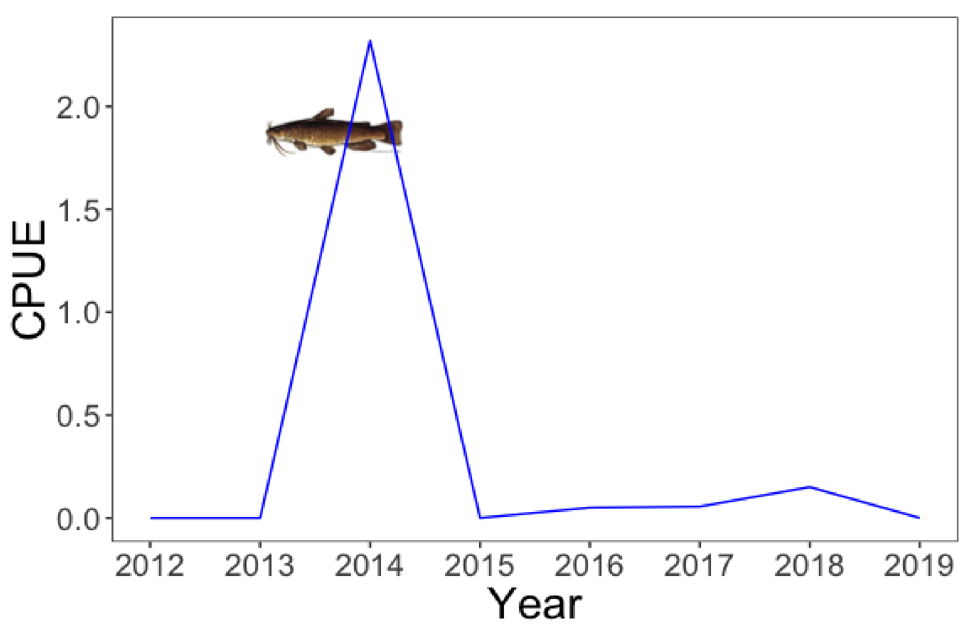


Figure 181. Fykes Annual Average over Fyke 1 and Fyke 2 Stations. *Ameiurus nebulosus* (blue). 2012-2019.

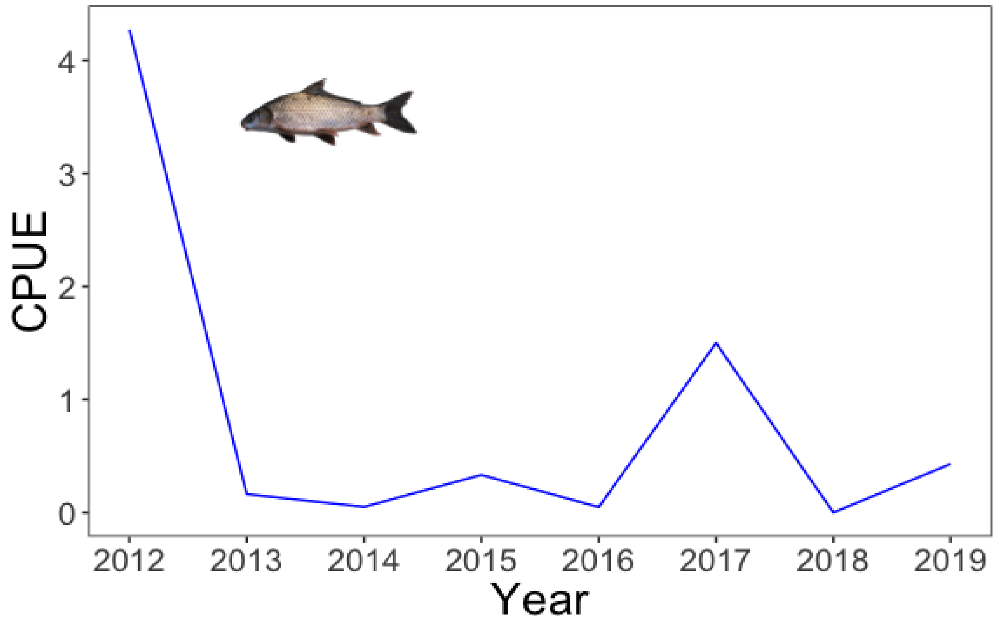


Figure 182. Fykes Annual Average over Fyke 1 and Fyke 2 Stations. *Carassius auratus* (blue). 2012-2019.

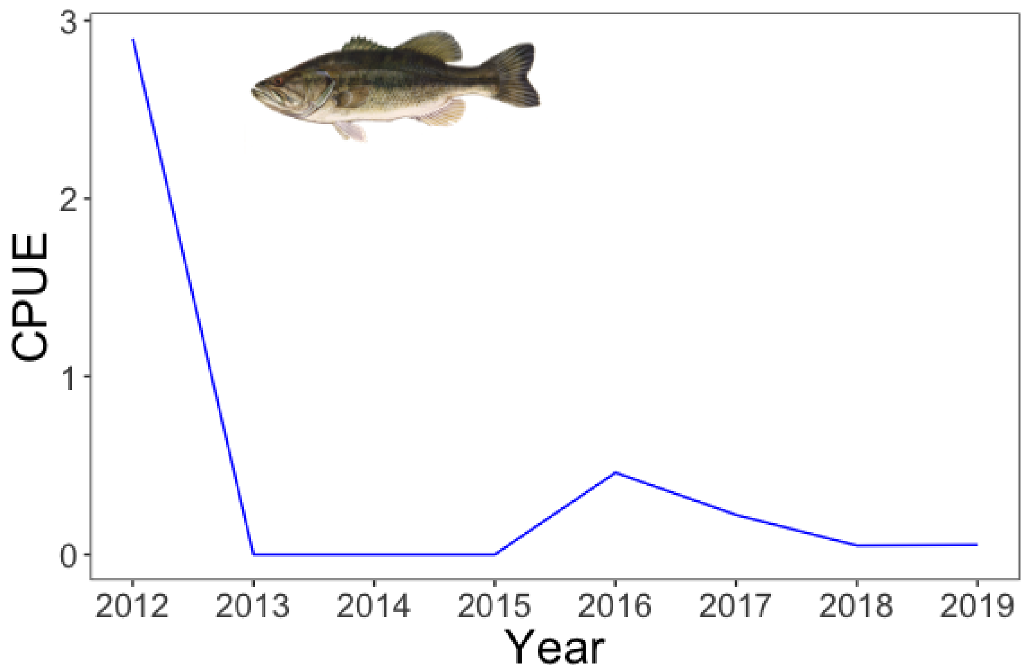


Figure 183. Fykes Annual Average over Fyke 1 and Fyke 2 Stations. *Micropterus salmoides* (blue). 2012-2019.

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, 2018 and 2019 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). In this index, calculated as $1-(\mathbf{\Sigma}\ (n_i/N)^2)$, the communities with higher diversity have higher values (approaching 1). The Simpson's Index of Diversity was 0.829 in 2019, and shows no increasing or decreasing trend over time. Calculating the index shows that the Cove represents a healthy and stable diversity. 2019 did show the fourth highest value since the start of the survey, and with an average annual value above 0.75 Gunston Cove harbors a diverse fish community. Overall, the fish species found in Gunston Cove are characteristic of Potomac River tributaries.

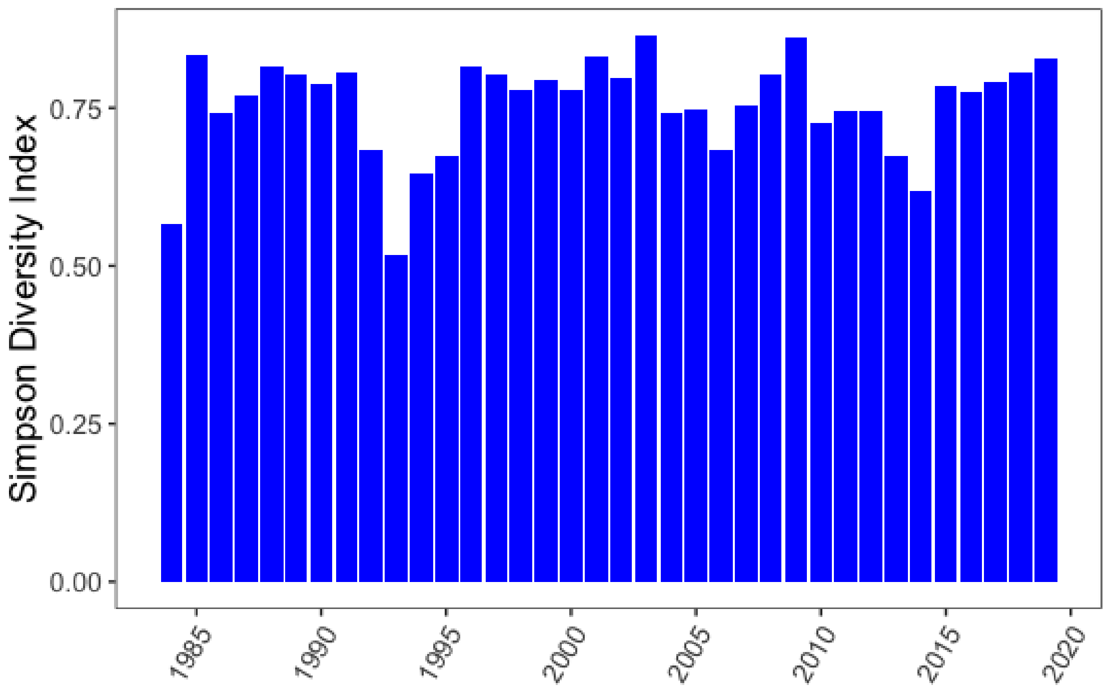


Figure 184. Simpson Diversity Index of fish species collected in Gunston Cove all years.

In 2019 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 in 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. The abundance of specimens collected with fyke nets was ip again in 2019, when SAV beds were present again.

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). In 2019 the Alosine abundance remained high. 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: 1994-2019

Benthic invertebrates have been monitored in a consistent fashion since 2009. Data from 2016-2019 are assembled below (Figure 185), and trends are generally consistent among years. The composition of the benthic macroinvertebrate community in the Potomac River mainstem (Station GC9) and Gunston Cove proper (Station GC7) 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 chironmids (midge larvae) are declining. In the river, sediments are coarser and are comprised of a mixture of bivalve shells (mainly the invasive bivalve *Corbicula fluminea*) 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 across all years (Figure 185). However, if Annelids are removed and we examine the other dominant taxon groups, we see a few different trends in dominant taxa between the two sites across years (Figure 185). In general, Gunston Cove proper (Station GC7) is dominated by the insect larvae of Chironomids (midges), while the Potomac River mainstem (Station GC9) is dominated by Gammarid amphipods. Amphipods have generally occurred sporadically at low levels in Gunston Cove proper (Station GC7). Amphipods are consistently the second most abundant macroinverterbrate at GC9 and the third most abundant macroinvertebrate at GC7. Isopods have been commonly found in the Potomac River mainstem (Station GC9) since 2010 and sporadically in Gunston Cove proper (Station GC7); 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. Bivalves and Gastropods also occur in low numbers at both sites, with approximately the same average number of Gastropods across sites and years. The Potomac River mainstem (Station GC9) has, on average, a higher abundance of Bivalves than GC7, mostly driven by the invasive Asian clam *Corbicula fluminea*. GC9 receives higher water flow and movement, which many species of Bivalvia require, and may help explain why there are higher abundances of Bivalvia located closer to the Potomac River. The consistent finding of even small numbers of taxa other than chironomids and oligochaetes in Gunston Cove proper (Station GC7) is encouraging and could be the result of improved water quality conditions in the cove.

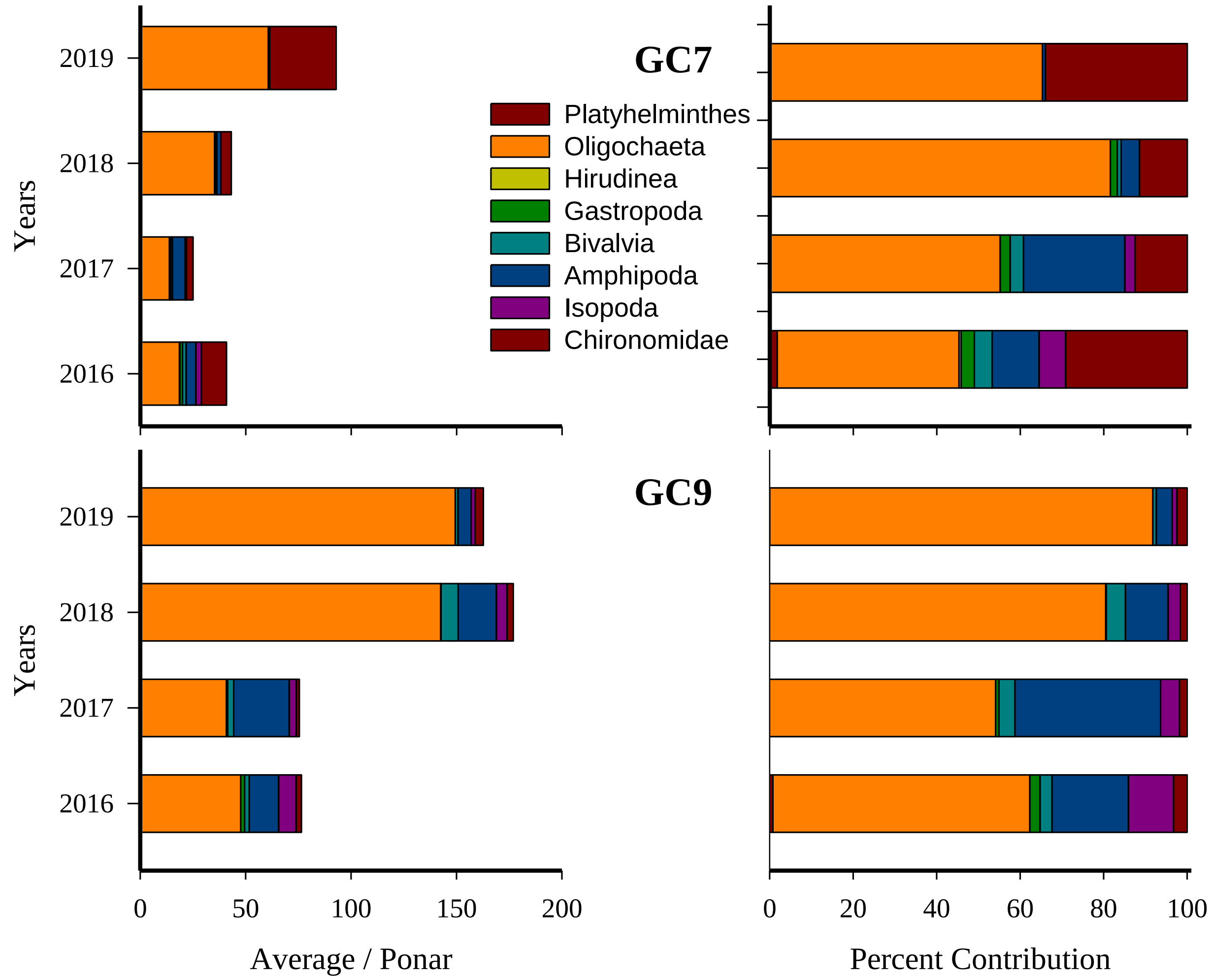


Figure 185. Average number per ponar sample (Left) and percent contribution (Right) of the eight dominant benthic invertebrate taxa in Gunston Cove embayment samples collected between 2016 and 2019 separated by site and year. Note the dominance of the Oligochaeta (worms).

H. Submersed Aquatic Vegetation (SAV) Trends: 1994-2019

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, 2011, and 2018. 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. In 2019, average Secchi disk transparency increased to pre-2018 levels and SAV rebounded to near record levels (Figure 186).

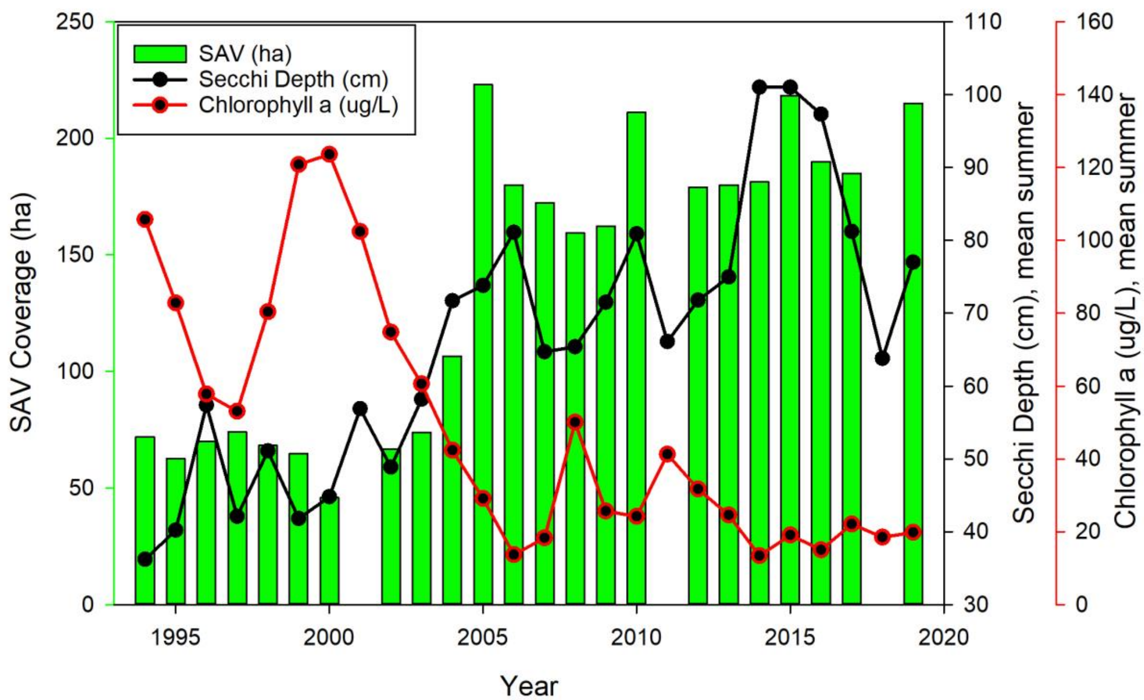


Figure 186. Gunston Cove SAV Coverage. Graphed with average summer (June-September) Depth-integrated Chlorophyll a (µg/L) and Secchi Depth (cm) measured at Station 7 in Gunston Cove.

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Anadromous Fish Survey of Pohick and Accotink Creeks 2019

Final Report
July 2020

By

Kim de Mutsert
Assistant Professor
Department of Environmental Science and Policy
Associate Director
Potomac Environmental Research and Education Center

George Mason University
Fairfax, VA

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.

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. 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 2019 in Pohick Creek and Accotink Creek.

Methods

We conducted weekly sampling trips from March 29 to May 31 in 2019. 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 10 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	Plankton nets	Cross-section	YSI	Accotink Creek Block net	Plankton nets	Cross-section	YSI
3/29/19	Y	Y	Y	Y	Y	Y	Y	Y
4/5/19	Y	Y	Y	Y	Y	Y	Y	Y
4/12/19	Y	Y	Y	Y	Y	Y*	Y	Y
4/19/19	Y	Y**	Y	Y	Y	Y**	Y	Y
4/26/19	Y	Y	Y	Y	Y	Y	Y	Y
5/03/19	Y	Y	Y	Y	Y	Y	Y	Y
5/10/19	Y	Y	Y	Y	Y	Y*	Y	Y
5/17/19	Y	Y	Y	Y	Y	Y	Y	Y
5/24/19	Y	Y	Y	Y	Y	Y*	Y	Y
5/31/19	Y	Y	Y	Y	Y	Y	Y	Y

*Plankton tows completed for 20 minutes instead of 10. **Plankton tows completed for 15 minutes instead of 10.

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. While we reported only on Alewife up to 2014, we discovered that Blueback Herring sightings are common enough in our samples in recent years 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 was 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 * 1680 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 2019 spanned a total of 10 weeks, during which we collected 40 ichthyoplankton samples, and 20 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 did not collect adult Hickory Shad specimens in Accotink Creek but did collect fourteen adult Hickory Shad specimens in Pohick Creek.

The abundance of confirmed *Alosa* larvae was lower than last year (399 versus 922 last year), but above average. The number of unidentified clupeid larvae was low (181 unidentified clupeids versus 4637 last year), which could be *Alosa* or *Dorosoma*; Gizzard Shad. Unidentified larvae are those too damaged to be identified to the species level, which usually occurs through a combination of high flow and high larval densities in the net. When flow and total larval abundance is lower, we generally have fewer we are unable to identify. We also collected 328 identified Gizzard Shad larvae. We found that most *Alosa* larvae consisted of Blueback Herring and Alewife larvae (Table 2). We did collect two Hickory Shad larvae as well, which we usually don’t collect.

Table 2. Larval and adult abundances of clupeids collected in both creeks in 2019.

	Accotink Creek				Pohick Creek			
Species	Larvae	Female	Male	All Adults	Larvae	Female	Male	All Adults
Blueback Herring	26	4	21	32	150	20	58	124
Hickory Shad	0	0	0	0	2	5	4	14
Alewife	37	8	40	70	181	7	101	181
Alosa sp.	1	0	0	1	2	0	0	1
Gizzard Shad	185	3	3	50	143	1	6	32
Clupeid sp.	76	0	0	0	105	0	0	0

We measured creek discharge at the same locations and times where ichthyoplankton samples were taken. The creeks showed different discharge patterns this year (Figure 2), with consistently higher discharge in Pohick Creek than in Accotink Creek, which is similar as in previous years. During the 70-day sampling period (which roughly coincides with the river herring spawning period), the total discharge was estimated to be on the order of 3.3 and 6.8 million cubic meters for Accotink and Pohick creeks, respectively (Table 3), which is a little lower than last year.

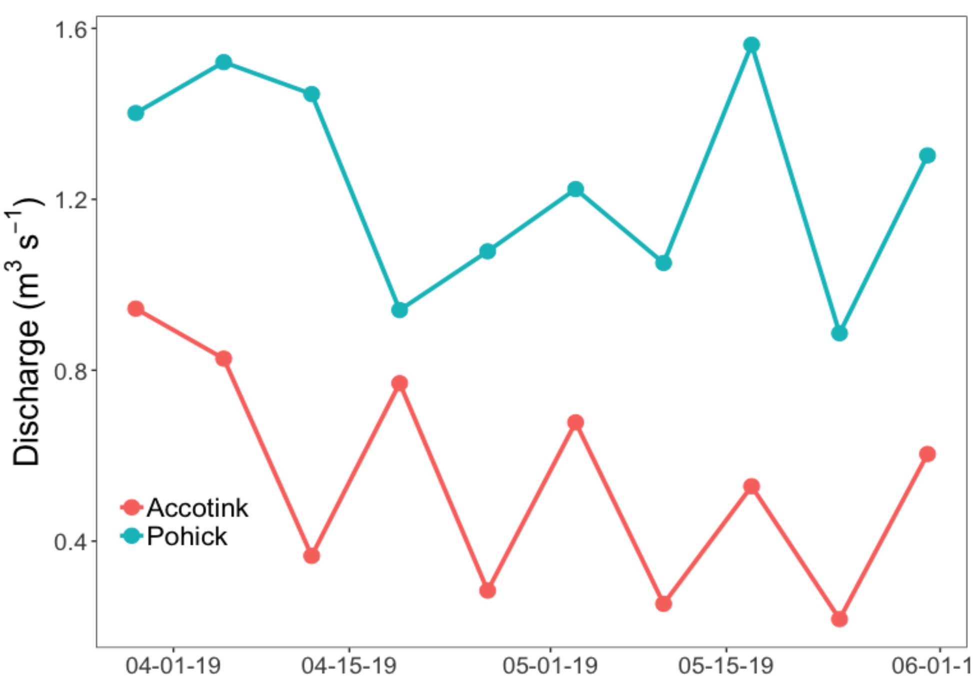

Figure 2. Discharge rate in m^3 s^{-1} measured in Pohick and Accotink creeks during 2019.

Larval density of Alewife exhibited a peak in Accotink Creek the second week of April (Figure 3a). Larval densities in Pohick Creek displayed a very high peak in the third week of 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 1.9 million and 15.4 million for Accotink Creek and Pohick Creek, respectively (Table 3). Larval density of Blueback Herring exhibited a peak in Accotink Creek the fourth week of April (Figure 3b). Larval densities in Pohick Creek displayed a high peak in the third week of April (Figure 3b). Blueback Herring larval density was lower than Alewife, but higher than previous years, leading to total larval production estimates of over 1 million and 9.6 million for Accotink Creek and Pohick Creek, respectively.

Table 3. Estimation of *Alosa pseudoharengus* and *A. aestivalis* fecundity and spawner abundance from Accotink and Pohick creeks during spring 2019.

Parameter	**Accotink**	**Pohick**
Mean discharge (m^3s^{-1})	0.547	1.241
Minimum discharge (m^3s^{-1})	0.217	0.887
Maximum discharge (m^3s^{-1})	0.944	1.562
Total discharge (m^3)	3,309,401	6,757,452
Alewife		
Mean larvae density (m^3)	0.562	2.281
Total Larval Production	1,859,361	15,415,188
Adult Mean Standard Length (mm)	223.8	228.7
Fecundity	71,965	75,250
Sex Ratio	0.114	0.039
Estimated number of females	56	51
Estimated total	490	1267
Blueback Herring		
Mean larvae density (m^3)	0.306	1.425
Total Larval Production	1,011,486	9,630,796
Adult Mean Standard Length (mm)	220.9	213.6
Fecundity	69,969	65,046
Sex Ratio	0.125	0.161
Estimated number of females	28	167
Estimated total number	224	868

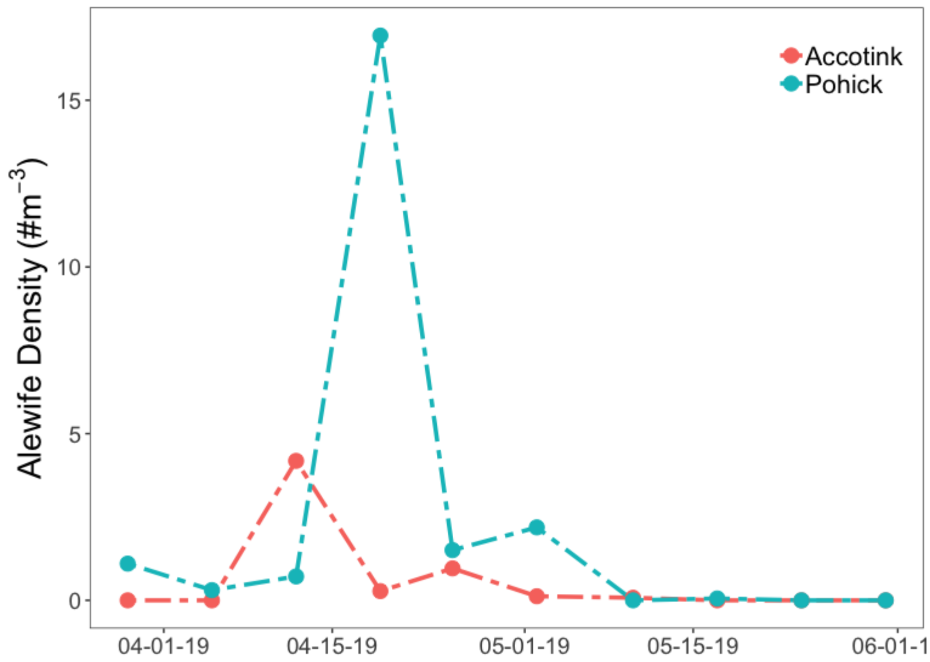

Figure 3a. Density of larval *Alosa pseudoharengus* in # m^{-3} observed in Pohick Creek and Accotink Creek in 2019.

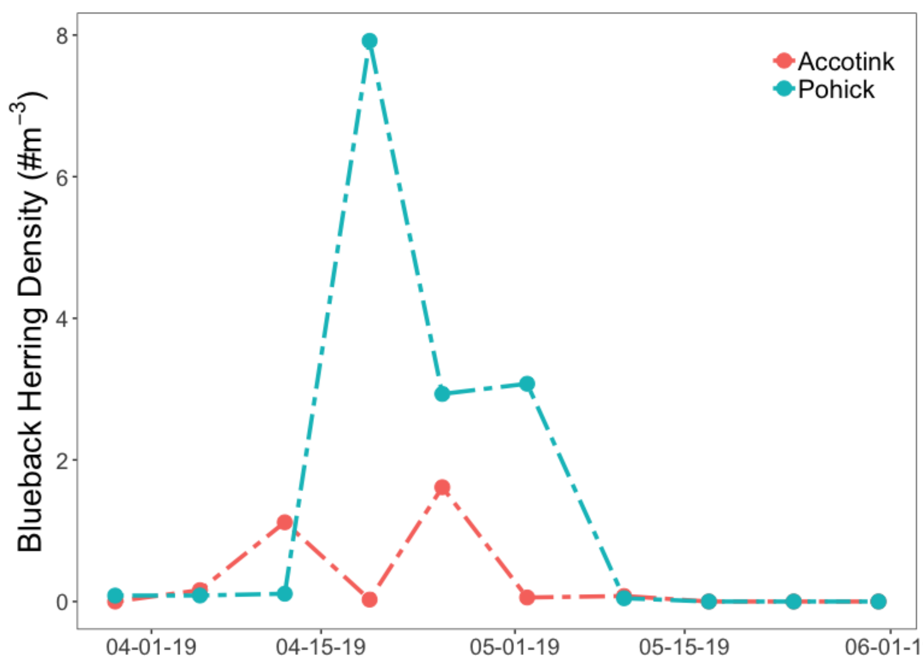

Figure 3b. Density of larval *Alosa aestivalis* in # m^-3& observed in Pohick Creek and Accotink Creek in 2019.

In the block nets, a moderate number of Alewife were collected (251, Table 2). This number was not as high as was collected in 2015 and 2018, but still high compared to other years than those two. Blueback Herring were collected in high numbers, but not to the extent of Alewife; 156 adults were collected. Of those captured, 148 Alewife and 103 Blueback Herring were sexed, providing us with sex ratios (Table 3). Skewed sex ratios in fish populations are common. The total abundance of spawning Alewife was estimated to be 1267 in Pohick Creek during the period of sampling, and 490 in Accotink Creek. The size of the spawning population of Blueback Herring was estimated to be 868 in Pohick Creek, and 224 in Accotink Creek this year.

Discussion

Summary 2019

We caught 148 adult Alewife and 103 adult Blueback Herring; we have positively identified Blueback Herring in this survey since 2011. We also collected 14 Hickory Shad. For Blueback Herring and Hickory Shad these numbers are on the same order of magnitude as what we collected in 2018, which was high because of the return of the successful 2015 year-class (Figure 4). Alewife numbers were lower in 2019 than they were in 2018 and 2015, but still above an average other year (Figure 4). The estimated size of the spawning population of Alewife is close to eighteen hundred fishes in the Gunston Cove watershed in 2019. We estimated a little more than half 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. While our sampling season is based on Alewife's spawning season, we seem to have encapsulated the Blueback Herring season as well in 2019, since we collected zero specimens of either species in the last four weks of the survey (Figure 3a and b). 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 were not fully capturing Blueback Herring's spawning period as their spawning season may have extended into early summer when we finished our survey. In 2019 the number of Alewife was not as high as it was in 2018, but still higher than years outside of the strong yearclass years 2015 and 2018. Blueback herring numbers, while not as high as they were in 2015, were higher in 2019 than they were in 2018. It could be the case that we better encapsulated the Blueback Herring spawning run in 2019, since we did not collect blueback herring anymore in the last four weeks of the survey. Overall both Alewife and Blueback Herring are doing better in the Gunston Cove tributaries than they were a decade ago.

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).

Table 4. The CPUE (number of individuals per net sample) of four Clupeid species that occur in this area captured with block net during the spawning season.

	Accotink Creek				Pohick Creek			
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	1.3	5.2	4.7	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	0.8	2.8	2.0	0.7	6.8	2.3
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
2019	3.2	0.0	7.0	5.0	13.8	1.6	20.1	3.6

For the Gunston Cove watershed, 2019 was a productive year for both Alewife and Blueback Herring (Figure 4). Table 4 shows a summary of adult clupeid abundance collected in block nets from 2008-2019. 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.

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.

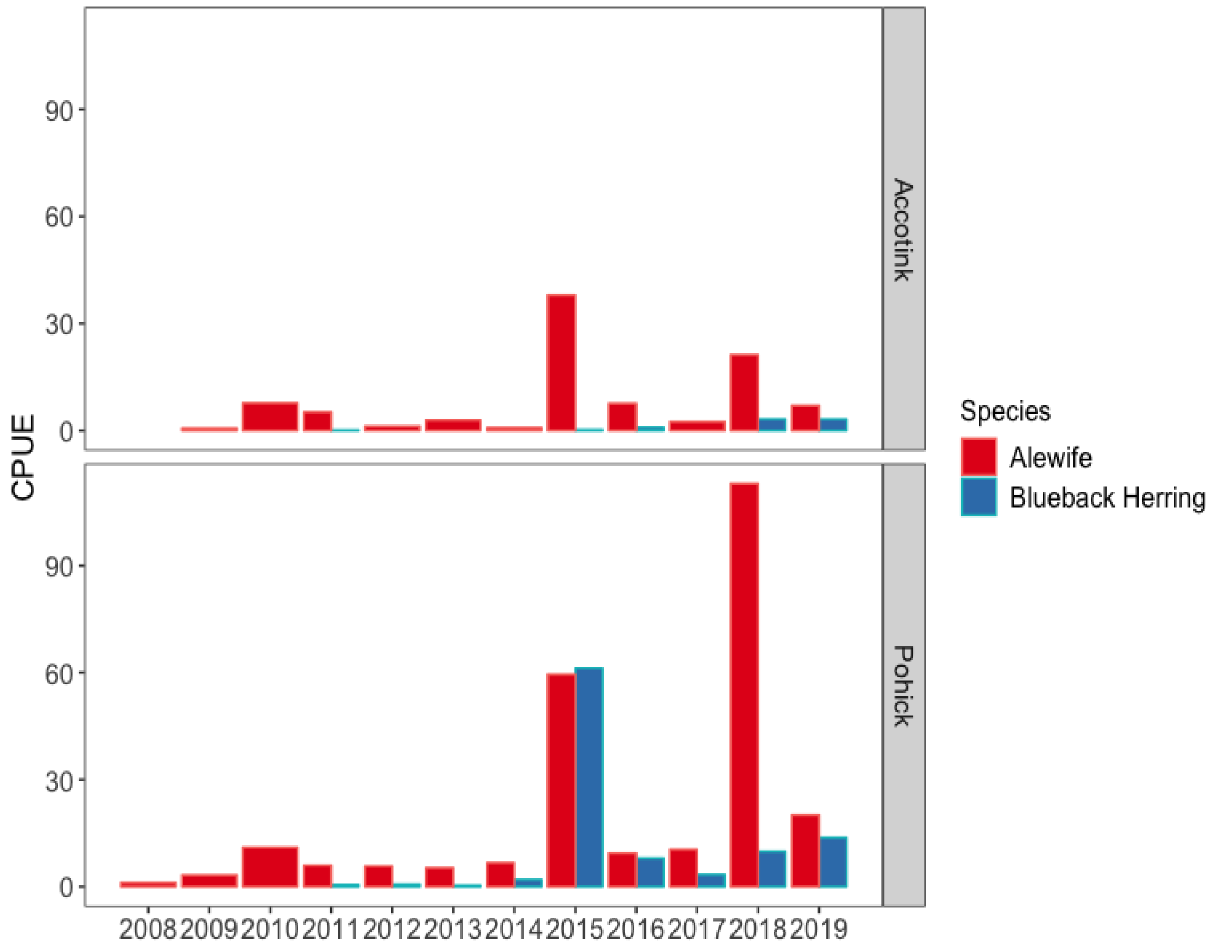

Figure 4. The CPUE (catch per unit effort; here number of individuals per net sample) of *Alosa pseudoharengus* and *A. aestivalis* collected with the block net in each year.

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