An Ecological Study of Gunston Cove

2022

FINAL REPORT

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by

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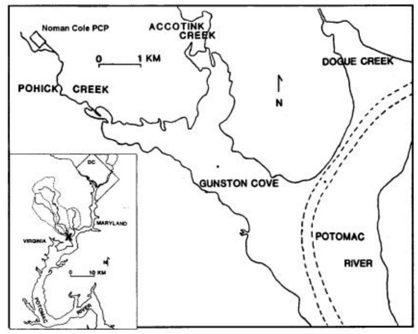
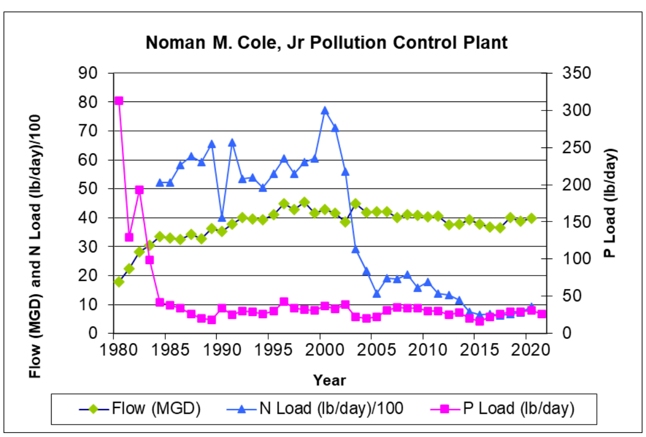


Gunston Cove is an embayment of the tidal freshwater Potomac River located in Fairfax County, Virginia about 12 miles (20 km) downstream of the I-95/I-495 Woodrow Wilson Bridge. The Cove receives treated wastewater from the Noman M. Cole, Jr. Pollution Control Plant and inflow from Pohick and Accotink 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 2021 in the context of the entire data record.

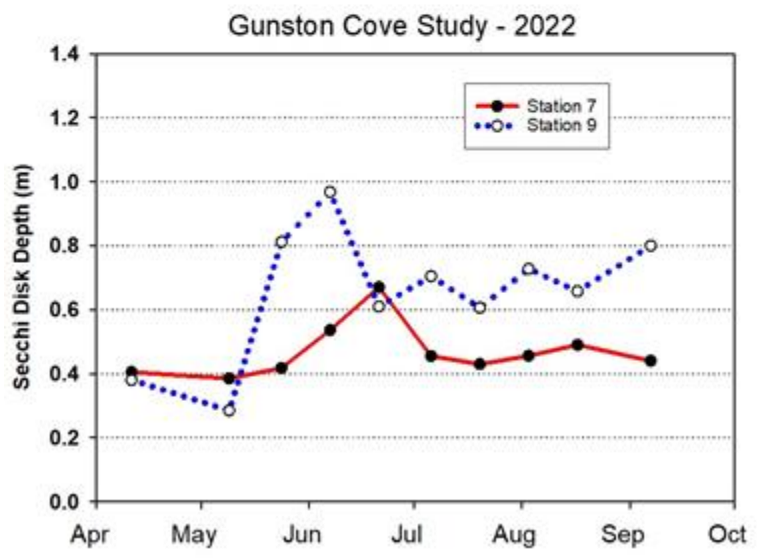
The Chesapeake Bay, of which the tidal Potomac River is a major subestuary, is the largest and most productive coastal system in the United States. The use of the bay as a fisheries and recreational resource has been threatened by overenrichment with nutrients which can cause nuisance algal blooms, hypoxia 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 37 year data record 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.

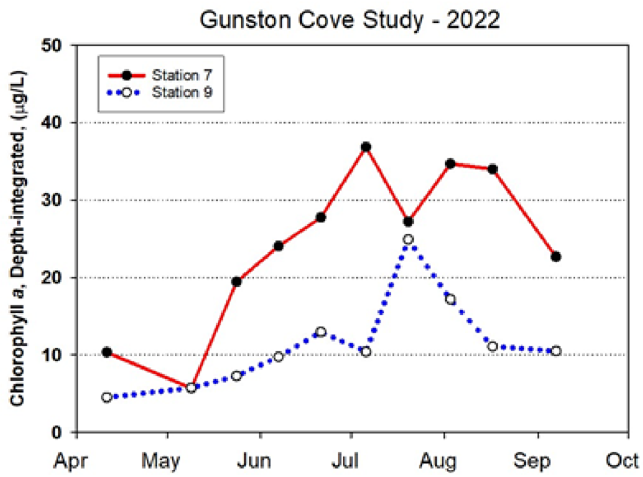
In 2022 temperature was above normal in all months. There were 34 days with maximum temperature above 32.2°C (90°F) as compared to 38 in 2021, both of which are well above the median number over the past decade. Precipitation was closer to normal in 2022 than in the extremely wet year 2018. However, it was again well above normal in 2022, especially in May and July. Sample dates in April, May, and early June could have been impacted by rainfall producing tributary flows. River flows which could impact the study area occurred in early May.



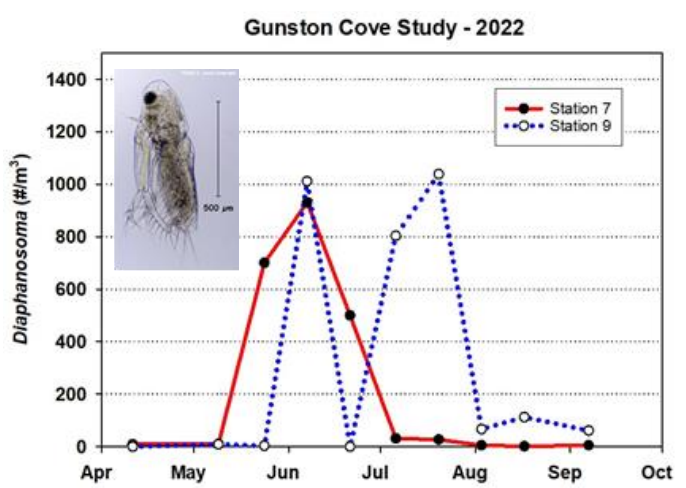
Mean water temperature was similar at the two stations with a pronounced dip in early June and a peak of about 30° in July. Specific conductance was mostly in the 250-400 range and increased through the year at both stations with little difference between the two on most dates. Dissolved oxygen saturation and concentration (DO) were consistently higher in the river in the spring and in the cove in the summer. Field pH patterns mirrored those in DO. Total alkalinity was generally higher in the river than in the cove with a general upward trend through the year. Water clarity as measured by Secchi disk transparency and light attenuation coefficient was generally better in the river than in the cove a trend that has become more common over the past several years. Values indicated only moderately good water clarity most of the year.

Ammonia nitrogen rarely exceeded the rather high detection limit of 0.1 mg/L making analysis of any temporal or spatial trends impossible. Nitrate values declined steadily through August at both stations with river values consistently about 0.5 mg/L than those in the cove. Nitrite was much lower overall. Organic nitrogen was generally fairly consistent through the year and about 0.1 mg/L higher in the cove than in the river. Total phosphorus was generally higher in the cove showed a little seasonal pattern. Soluble reactive phosphorus was consistently higher in the river, but showed little consistent seasonal trend. N to P ratio was about 20 in the river and 10 in the cove, a range which is still indicative of P limitation of phytoplankton and SAV. BOD was generally higher in the cove than in the river. TSS was consistently between 10 and 30 in the river and 20 to 50 in the cove and varied a lot from week to week. VSS showed similar spatial and temporal patterns.

In the cove algal populations as measured by chlorophyll *a* increased steadily through May and June reaching a peak of about 40 µg/L in late June and remaining above 30 µg/L through August. In the river there was a steady increase through spring and early summer reaching about 25 ug/L in late July. In 2022 phytoplankton density in the cove was dominated by cyanobacteria on all dates. *Oscillatoria* was the dominant cyanobacterial taxon early in the year, but was displaced by *Gomphosphaeria* from late June on. In terms of biovolume the dominant group were the diatoms with the most abundant species being the filamentous diatom *Melosira* on most dates. The dominant group in terms of cell density in the river was again the cyanobacteria and the dominant taxon on many dates was either *Oscillatoria* or *Gomphosphaeria.* In terms of biovolume diatoms were again were the dominant group on most dates as in the cove. In the spring and early summer *Melosira* shared dominance with *Cocconeis* and *Surrirella*. In both the cove and the river, the peak in cell density occurred in late June.



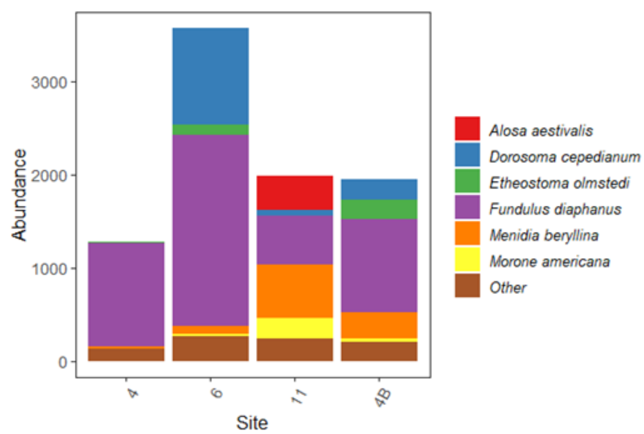
Rotifers continued to be the most numerous microzooplankton in 2022. Rotifer densities in the cove exhibited two distinct peaks each dominated by a different genus, *Filinia* in late May and *Brachionus* in late June. Rotifer densities were consistently lower in the river than in the cove with *Brachionus a*s the dominant. *Bosmina*, a small cladoceran exhibited a very distinct peak in the cove in mid-May, but otherwise values were very low. *Diaphanosoma*, a larger cladoceran, was moderately abundant in both areas with maxima in both cove and river in early June and a second similar maximum near 1000/m^3 in the river in mid July. *Daphnia* displayed much higher than normal peaks in 2022. Cove levels were over 3000/m^3 in late May and the river reached 1500/m^3 in mid June.. *Leptodora* exhibited a very strong peak in the cove in late May at over



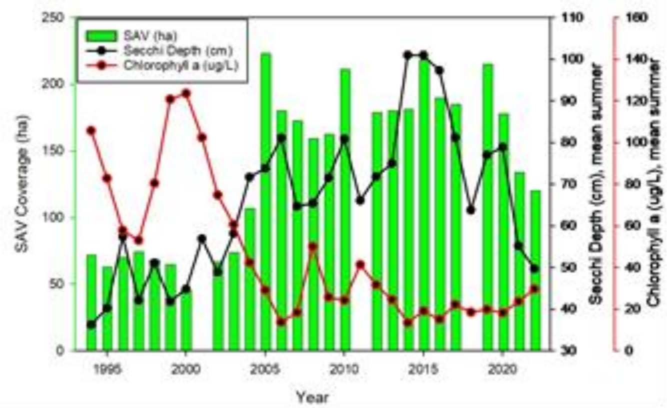
2500/m^3. Copepod nauplii followed a clean unimodal pattern in the river exceeding 200/L in late June. Values were somewhat lower and more variable in the river. The calanoid copepod *Eurytemora* was quite abundant in the cove in mid-May attaining 6000/m^3, but was much lower for the rest of the year. *Eurytemora* attained a value of about 3000/m^3 in the river in mid-June. A second calanoid *Diaptomus* was found at much lower levels. *Mesocyclops edax* had a strong maximum in the river in mid-July of about 9000/m^3, but otherwise was quite rare.

In 2022 ichthyoplankton was dominated by clupeids, most of which were Gizzard Shad (22%), Alewife (8.7%), and Blueback Herring (8.3). White Perch was found in relatively high densities (13.4%), mostly found in the Potomac mainstem, confirming its affinity for open water. Inland Silverside was also relatively abundant (3.4%). The highest density of fish larvae occurred mid May, which was driven by a high density of Clupeid larvae. White perch larvae also reached a maximum in May.

In trawls White Perch dominated at 76%, followed by Spottail Shiner at 8%, and then Bay Anchovy at 5.7%. No other species exceeded 5%. White Perch was by far the most abundant species and was found in all months at all stations. We collected a lot less Blue Catfish than in 2018, but still found 9 in the mainstem and 10 in the cove. In previous years we found more Blue Catfish in the mainstem versus the cove, which if true would suggest that the coves could serve as refuges for native catfishes. We collected 1 native bullhead catfish and 6 white bullheads in the cove and none in the mainstem. In seines, the most abundant species in 2022 was Banded Killifish comprising 53% of the catch (graph to the right). 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). Other taxa with high abundances were Gizzard Shad (15%), and Inland Silverside (11%). Abundances remained substantial throughout the sampling season. In fyke nets Inland Silverside was the dominant species in 2021 with 26% of the total catch. Sunfish (*Lepomis* species lumped together) were also abundant at 24% and Banded Killifish at 19%. White perch were rare in the fyke nets.



As in most previous years, oligochaetes were the most common invertebrates collected in ponar samples in 2022. Chironomids (midge larvae) were second most dominant in the cove and third most dominant in the river. The second most numerous taxon in the river was Amphipoda. Multivariate analysis showed a clear and consistent difference between cove benthic communities and those in the river. Shells were consistently the most abundant large substrate in river benthic samples. In the cove both shells and plant debris were abundant.



Coverage of submersed aquatic vegetation (SAV) in 2022 was down from the higher 2019 levels, but still within the range of post 2004 values. As in recent years, *Hydrilla*, coontail, and spiny naiad were the most abundant SAV taxa. Standardized 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 indicates that the "clear water" state was in place through 2020 with improved water clarity (Secchi depth), lower phytoplankton (chlorophyll *a*), and greater coverage of SAV. The last two years show a clear decrease in water clarity as revealed by Secchi Depth and declines in SAV, raising concerns that SAV may be struggling again as a result of low water clarity. This as chlorophyll levels continue to remain low, but TSS levels are showing an upswing. The exact cause of the higher TSS levels needs to be examined.

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 2022 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, were quite abundant in 2018 and maintained a presence in 2019-2022. Blue Catfish are regarded as rather voracious predators and may negatively affect the food web. Other catfish are down significantly now that the Blue Catfish is present.

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 2022 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, Inland Silverside and Banded Killifish in the SAV beds. In addition to the effect of SAV the increased presence of 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.

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 and 2020 data indicate that the ecosystem was resilient and recovered to .

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. The decrease in water clarity observed in 2021 and 2022 should be carefully monitored in the 2023 data. The trend may be responsible for a decreasing trend in SAV in the cove.
3. Two aspects of the program should be reviewed.
    a. In 2016 phytoplankton cell count 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.

4. 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.
5. 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.
6. We have instituted some improvements to the benthic monitoring program including the quantitative characterization of larger (>5 mm) particles in the samples which we expect to help explain the variations we see in benthic communities between samples and station. This should continue.

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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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 and Shahram Mohsenin for their advice and cooperation during the study. 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. Saiful Islam conducted phytoplankton counts. Claire Buchanan served as a voluntary consultant on plankton identification. Natalie Lapidot-Croitoru and Anne Reynolds were vital in handling budget, personnel and procurement functions.

We thank Rachel Kelmartin for taking a large role in the field collection and laboratory processing of these fishes, the work would not have been completed without her. Finally, we thank the other field technicians and student workers from the George Mason Fisheries Ecology Lab.

Thanks also go to lab and field workers Beverly Bachman, Chelsea Gray, Alex Mott, Sam Mohney, Daya Stratton-Hall, and Daria Maslyukova.

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.

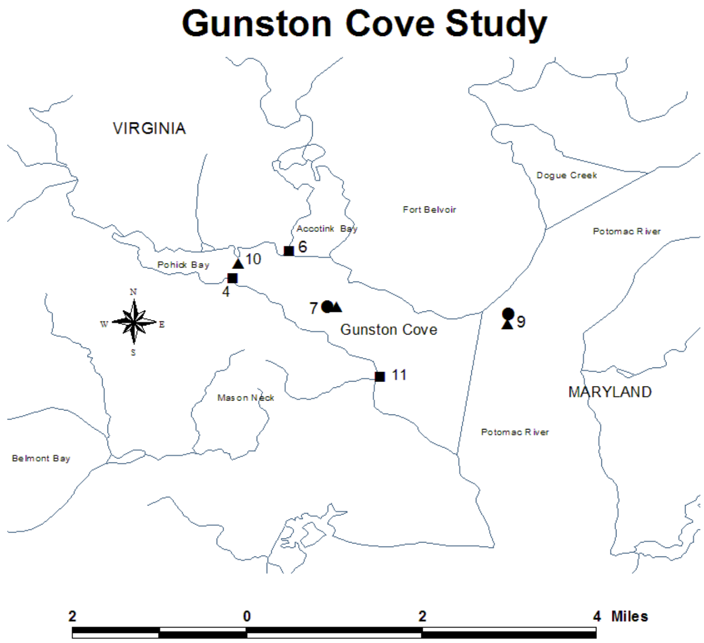


Figure 1a. Gunston Cove area of the Tidal Potomac River showing sampling stations. Circles (●) represent Plankton/Profile stations, triangles (▲) represent Fish Trawl stations, and squares (■) represent Fish Seine stations.

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

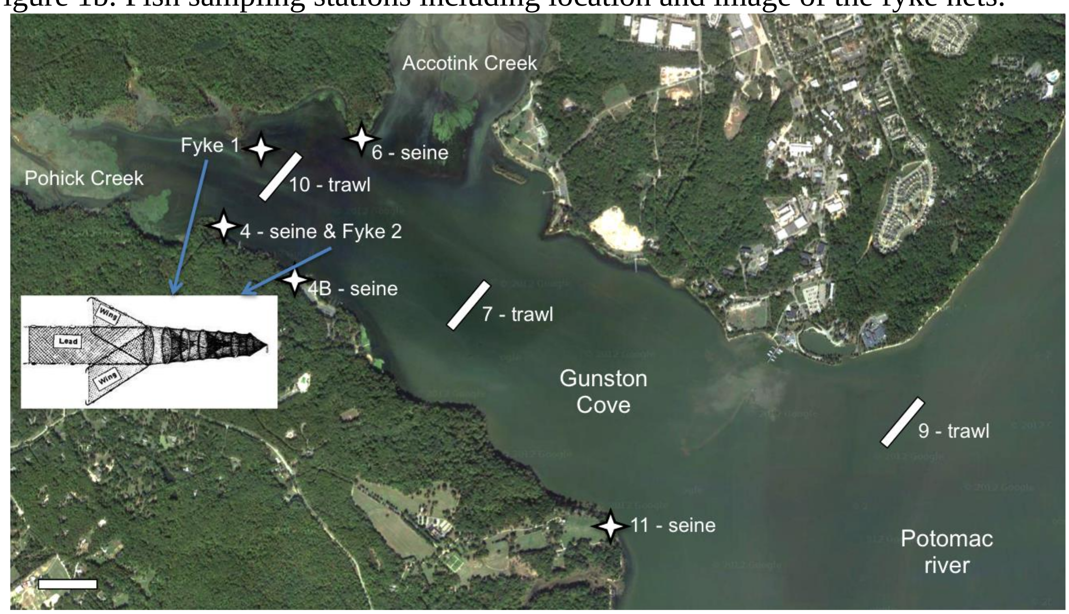


Table 1
Sampling Dates and Weather Data for 2022

Date	Type of Sampling G	F	N	T	S	Y	Avg Daily Temp (ºC) 1-Day	3-Day	Precip (cm) 1-Day	3-Day
Apr 11	G	F					10.6	10.0	0	0.10
Apr 29				3	4	2	12.2	11.5	0	0
May 9	G						13.3	11.9	0	3.28
May 13				3	4	2	19.4	18.5	0.36	0.36
May 17			N				21.7	20.9	0	1.80
May 24	G	F					16.7	21.5	0.81	4.62
May 26				3	4	2	18.9	17.8	0	0.81
Jun 7	G						21.7	22.2	0.51	0.51
Jun 9				3	4	2	25.0	23.9	0.15	0.71
Jun 21	G	F					23.9	22.4	0	0
Jun 23				3	4	2	21.1	23.5	0.56	4.78
Jun 28			N				23.3	25.2	0	0.53
Jul 6	G						28.9	27.0	0	0.23
Jul 14				3	4	2	26.7	26.1	0	1.12
Jul 20	G	F					28.3	28.1	0	0
Jul 25			N				28.9	29.3	0.66	0.66
Jul 28				3	3	2	28.9	27.0	0.51	0.51
Aug 3	G						28.9	27.6	0	1.30
Aug 11				3	3	2	25.6	28.0	0	1.32
Aug 17	G	F					23.9	23.1	0	0.03
Aug 30			N				27.2	27.8	0.36	0.36
Sep 7	G	F					23.3	25.2	0.05	2.36
Sep 15				3	3	2	22.8	23.0	0	0
Sep 27			N				19.4	20.0	0	0.03

Type of Sampling: B: Benthic, G: GMU profiles and plankton, F: nutrient and lab water quality by Fairfax County's Noman Cole Laboratory, T: fish collected by trawling, S: fish collected by seining, Y: fish collected by fyke net. Numbers in T, S, and Y columns indicate how many stations were sampled on each date. All of the above samples were collected by GMU personnel. N: samples collected and analyzed for nutrient and lab water quality by Fairfax Co.'s Noman Cole Laboratory.

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 EXO data sonde. 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, mid-depth, 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 processed using an overnight soaking procedure which has been shown to give comparable results to the traditional homogenization process. (Huntley et al. 1987). The filters had been stored in the freezer in 20 mL plastic scintillation vials pending analysis in October. 15 mL of 90% acetone was added to each vial and the vials were shaken.

They were placed in the refrigerator overnight. The next day they were mixed and assayed fluorometrically.

Chlorophyll *a* concentration in the extracts was determined fluorometrically using a Turner Designs Trilogy fluorometer configured for chlorophyll analysis as specified by the manufacturer. The instrument was calibrated using standards obtained from Turner Designs. Chlorophyll was determined and then after acidification with 2 drops of 10% HCl pheophytin was determined.

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:

$$\text{Zooplankton } (\#/\text{L or } \#/\text{m}^3) = NV_s/(V_cV_f)$$

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. 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 are found in Table 1. Typically, each trawl site is sampled once per sampling event. When a trawl gets stuck our CPUE is adjusted to account for the fact that the net sampled for a shorter duration.

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. We conducted seine sampling bimonthly from mid-April. Stations 4, 6, and 11 have been sampled continuously since 1985. 4B was added to the sampling stations since 2007 because extensive SAV growth interferes with sampling station 4 in late summer. Station 4B is a routine station now, also when seining at 4 is possible, resulting in a maximum of 4 seining sites per sampling trip. This allows for comparison between 4 and 4B.

Fyke nets are set at station fyke 1 (near trawl station 10) and station fyke 2 (near seine station 4). Setting fyke nets when seining and trawling is still possible allows 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).

After collection, 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/glycerin.

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 - 2022

In 2022 temperature was above normal in all months (Table 2). There were 34 days with maximum temperature above 32.2°C (90°F) in 2022 which was slightly less than in 2020 and 2021, but well above the median number over the past decade. Precipitation was closer to normal in 2022 than in the extremely wet year 2018. However, it was again well above normal in 2022, especially in May and July.

Table 2. Meteorological Data for 2022. National Airport. Monthly Summary.

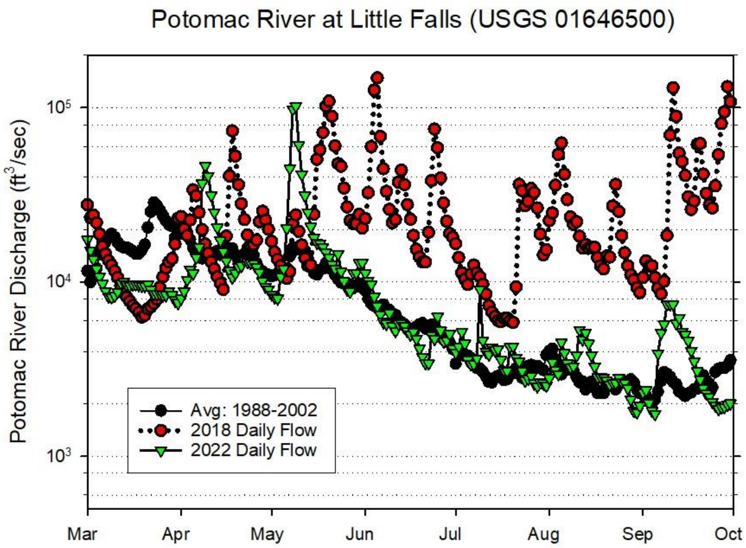
MONTH	Air Temp (°C)		Precipitation (cm)	
March	10.0	(8.1)	7.0	(9.1)
April	13.6	(13.4)	9.7	(7.0)
May	19.6	(18.7)	16.2	(9.7)
June	24.4	(23.6)	7.5	(8.0)
July	26.8	(26.2)	19.3	(9.3)
August	26.4	(25.2)	6.2	(8.7)
September	22.4	(21.4)	5.8	(9.6)

Note: 2022 monthly averages or totals are shown accompanied by long-term monthly averages (1971-2000). Source: Local Climatological Data. National Climatic Data Center, National Oceanic and Atmospheric Administration.

River and tributary stream flow in 2022 was generally near or slightly below normal (Table 3).

Table 3. Monthly mean discharge at USGS Stations representing freshwater flow into the study area. (+) 2022 month > 2x Long Term Avg. (-) 2022 month < ½ Long Term Avg.

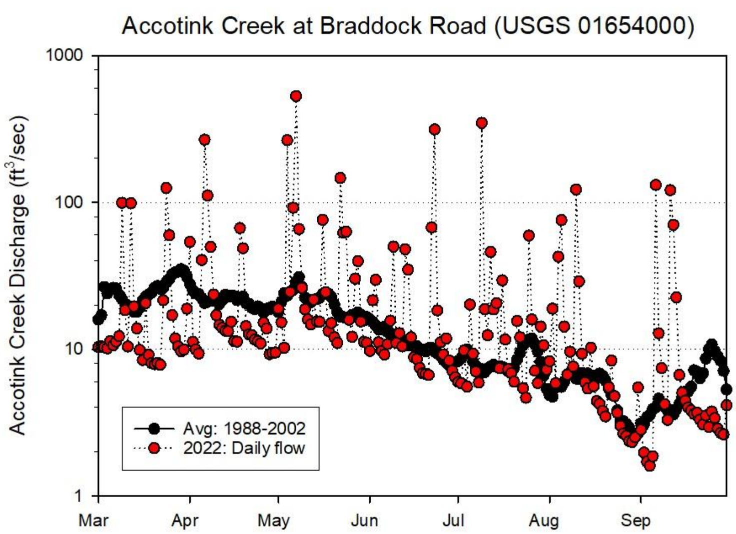
	Potomac River at Little Falls (cfs)		**Accotink Creek at Braddock Rd (cfs)**	
	2022	**Long Term Avg.**	**2022**	**Long Term Avg.**
March	9738 (-)	23600	22.9	42
April	16290	20400	31.0	36
May	23058	15000	55.0	34
June	5787	9030	26.4	28
July	3724	4820	24.5	22
August	3174	4550	14.1	22
September	3605	5040	14.9	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: 2022. Potomac River at Little Falls (USGS Data). Month tick is at the beginning of the month.

These same patterns were seen in the graphs of daily river flow when compared to long-term averages (Figure 2). The long-term average shows a steadily decreasing trend from April through September. In 2022 this general seasonal pattern was observed except for a notable surge in early May which had the potential to strongly impact the ongoing growth of SAV and plankton in the river. 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 scattered across the year.



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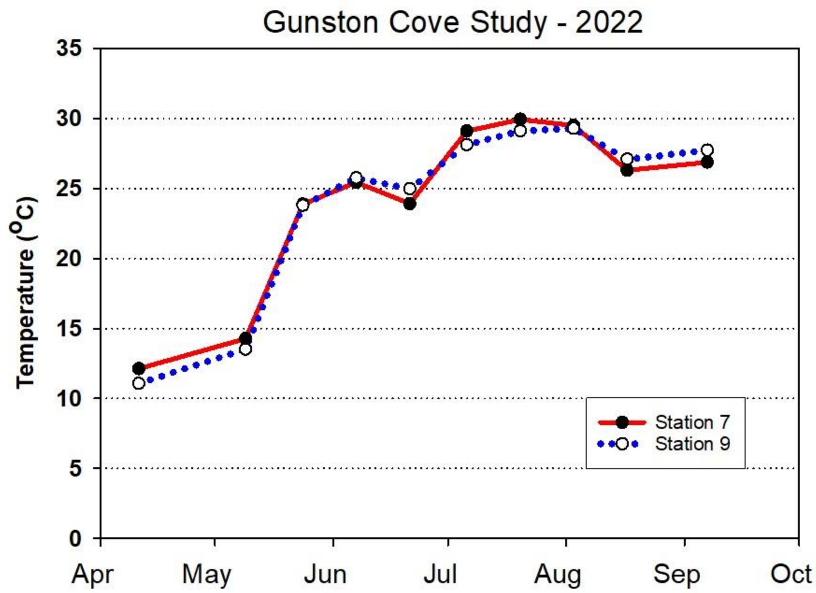
In the Gunston Cove region of the tidal Potomac, freshwater discharge is occurring from both the major Potomac River watershed upstream (measured at Little Falls) and from immediate tributaries. The cove tributary for which stream discharge is available is Accotink Creek. Accotink Creek delivers over 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.

Figure 3. Mean Daily Discharge: 2022. Accotink Creek at Braddock Road (USGS Data).

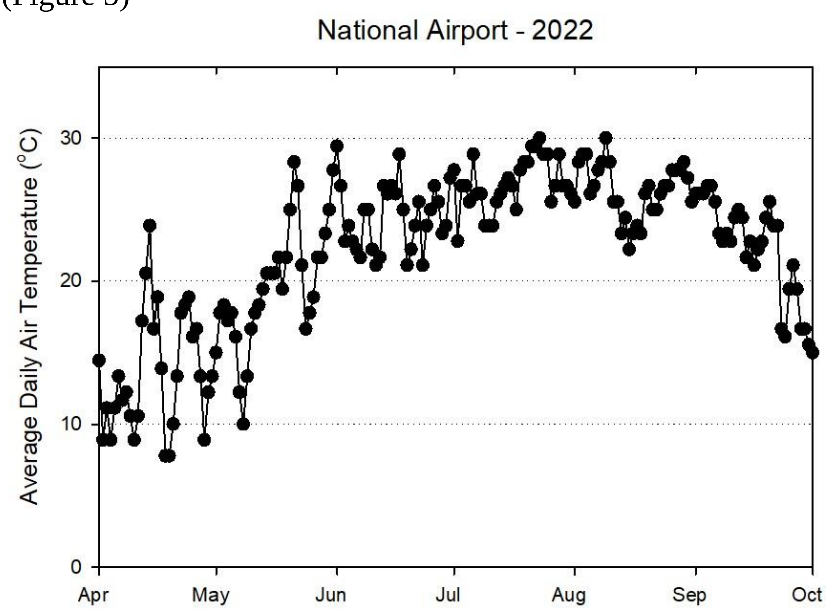
B. Physico-chemical Parameters – 2022



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 (^oC). GMU Field Data. Month tick is at first day of month.

In 2022, water temperature followed the typical seasonal pattern at both sites with the exception of a slight cooling in late June (Figure 4). Both sites were between 25°C and 30°C from July through September with a high of 30°C in early July. For most of the study period, the two stations showed very similar water temperatures and fairly closely tracked air temperature (Figure 5)



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

Figure 5. Average Daily Air Temperature (^oC) at Reagan National Airport.

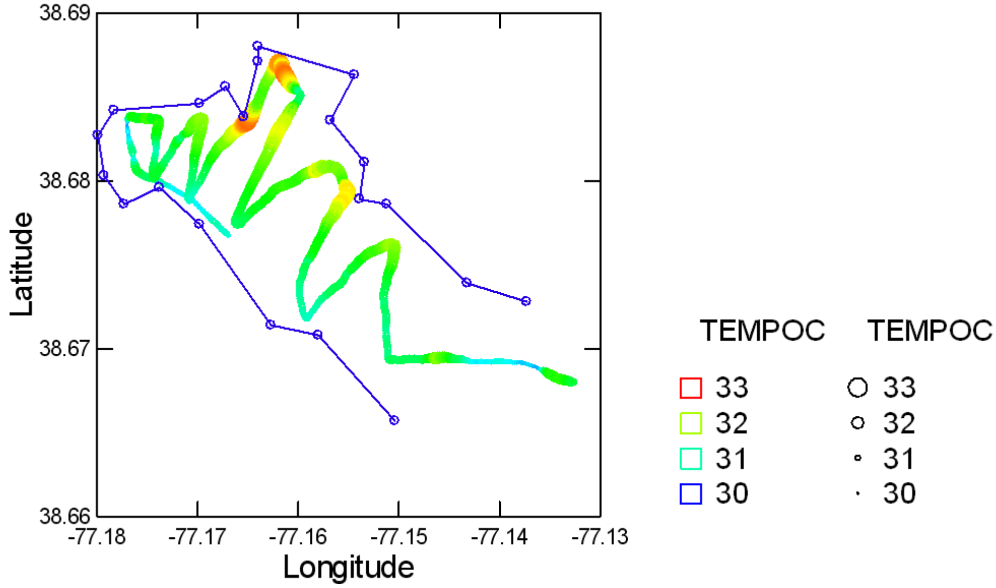


Figure 6. Temperature (ºC) observed in transects across Gunston Cove during data mapping cruise on August 3, 2022.

Temperature and Specific Conductance were measured during data mapping cruise on August 3, 2022 to assess spatial patterns in Gunston Cove. Temperature was highest in Accotink Creek and along the north side of Gunston Cove (Figure 6). Specific conductance showed somewhat higher values in Pohick Bay and outer 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.

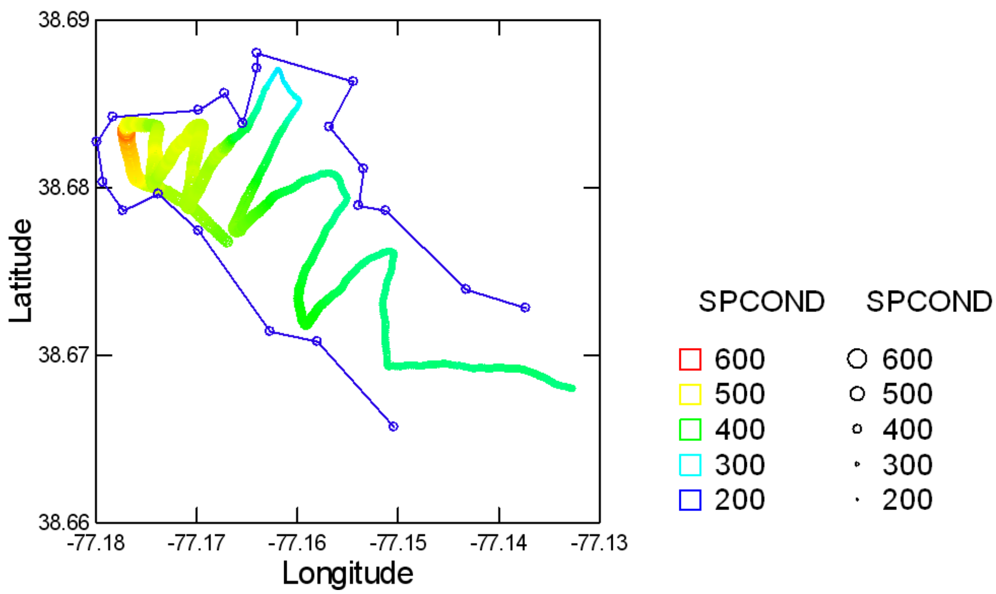


Figure 7. Specific Conductance (uS/cm) observed in transects across Gunston Cove during data mapping cruise on August 3, 2022.

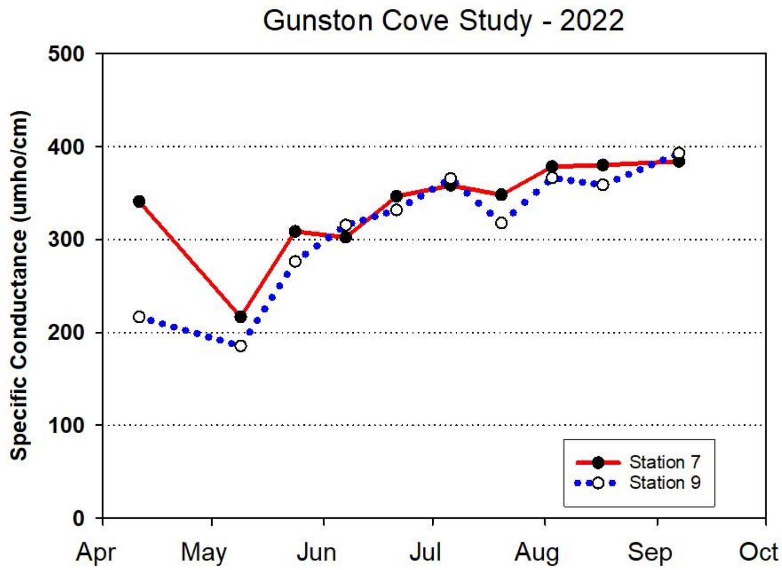
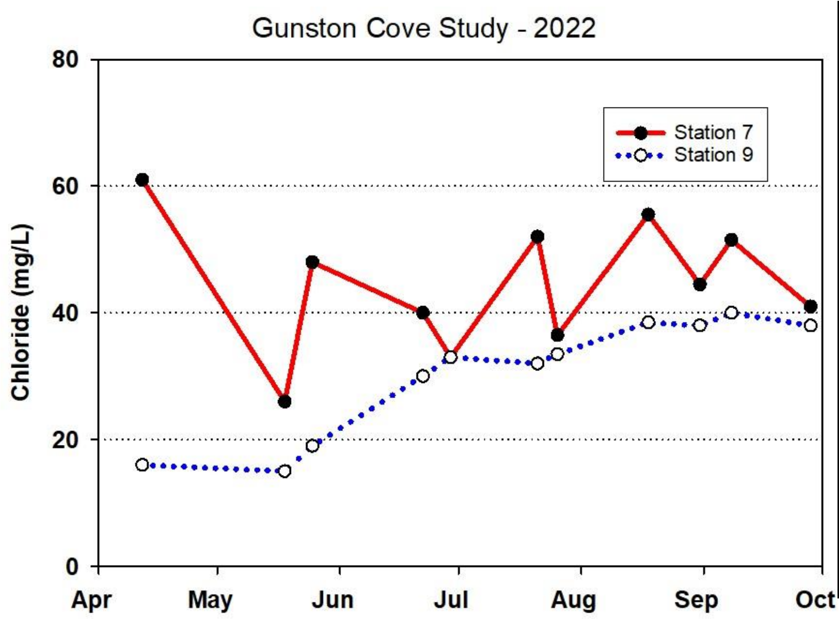


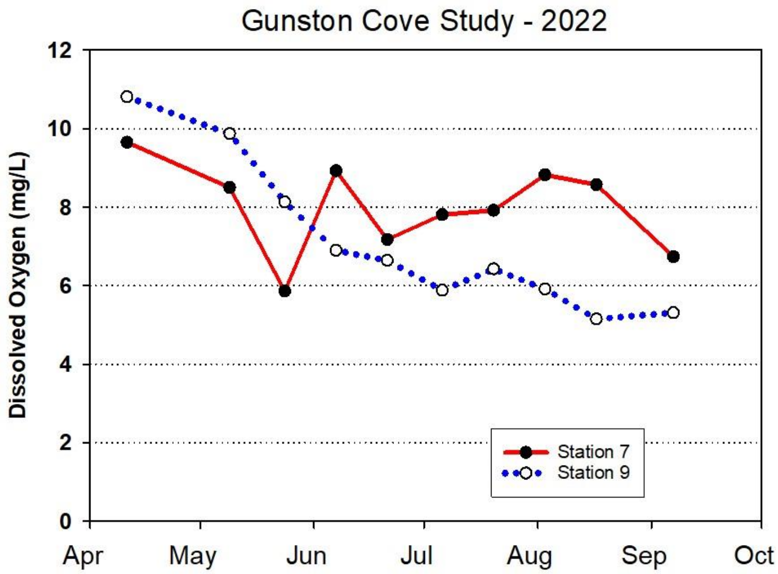
Figure 8. Specific Conductance (uS/cm). GMU Field Data. Month tick is at first day of month.

Specific conductance was mostly in the 200-400 range (Figure 8). In April Station 7 was almost twice the value at Station 9 whereas during the rest of the year, their values were almost identical. A gradual upward trend was observed for conductivity from May through September. Chloride ion was consistently higher at Station 7, probably due to the Noman Cole effluent, but all 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.

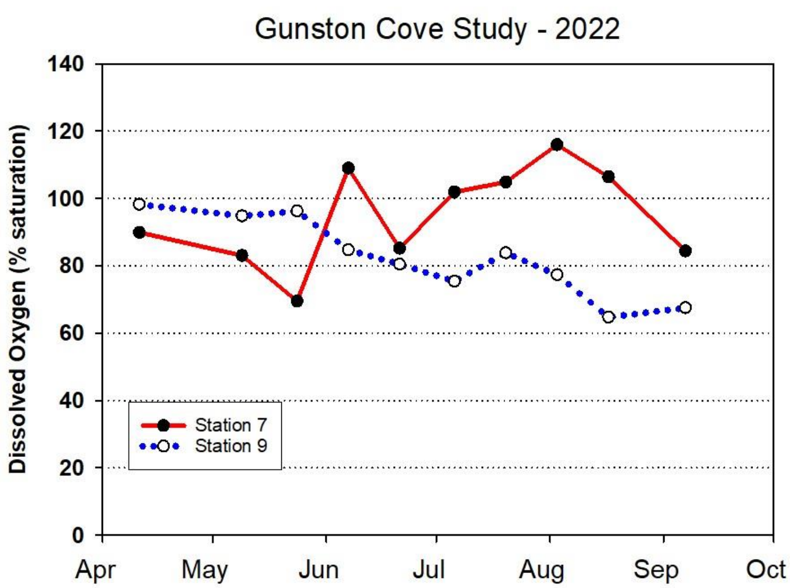
Figure 9. Chloride (mg/L). Fairfax County Lab Data. Month tick is at first day of month.



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

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

Dissolved oxygen in mg/L showed a gradual decline through the year at Station 9 while at Station 7 dissolved oxygen was fairly stable though most of the year (Figure 10). Figure 11 shows that dissolved oxygen levels in the cove were slightly above 100% for most of the summer 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 probably attributable to the deep water-column meaning that phytoplankton spend most of their time below the photic zone.



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.

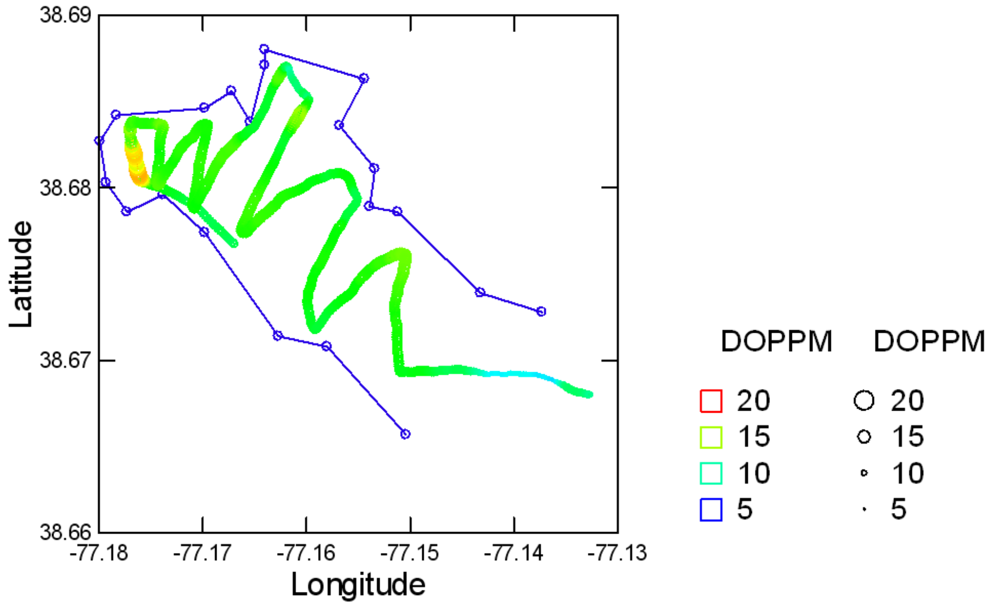


Figure 12. Dissolved Oxygen (mg/L) observed in transects across Gunston Cove during data mapping cruise on August 3, 2022.

Dissolved oxygen levels were highest in the upper part of Pohick Bay (Figures 12&13). The supersaturated DO values indicated strong photosynthetic activity probably due to dense SAV in this area.

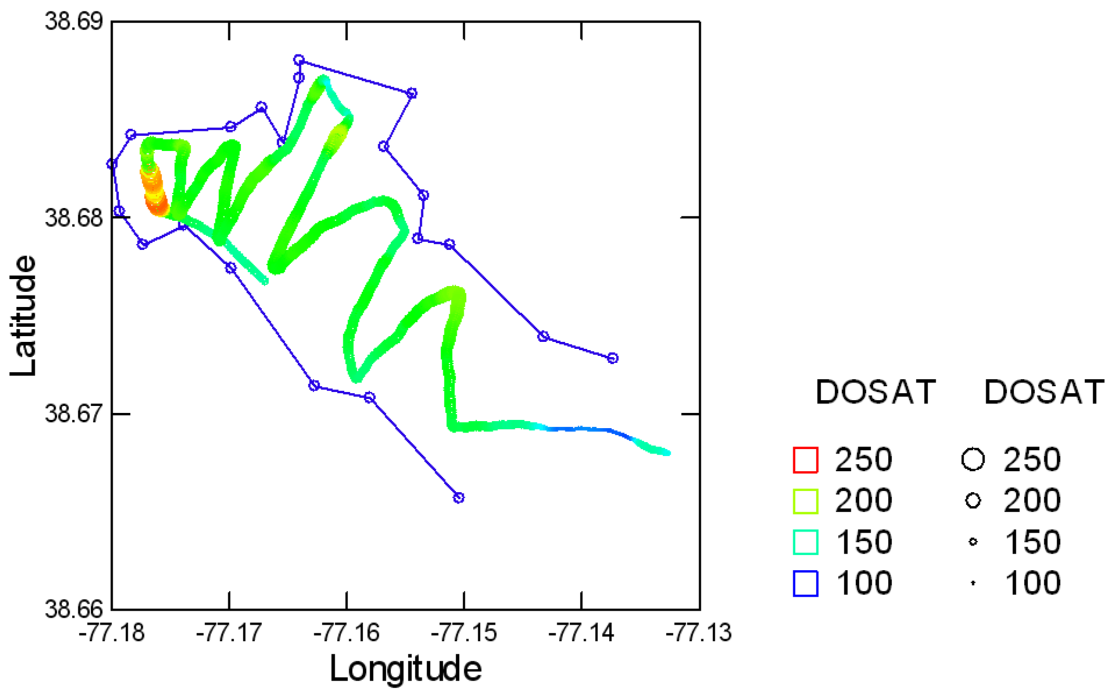
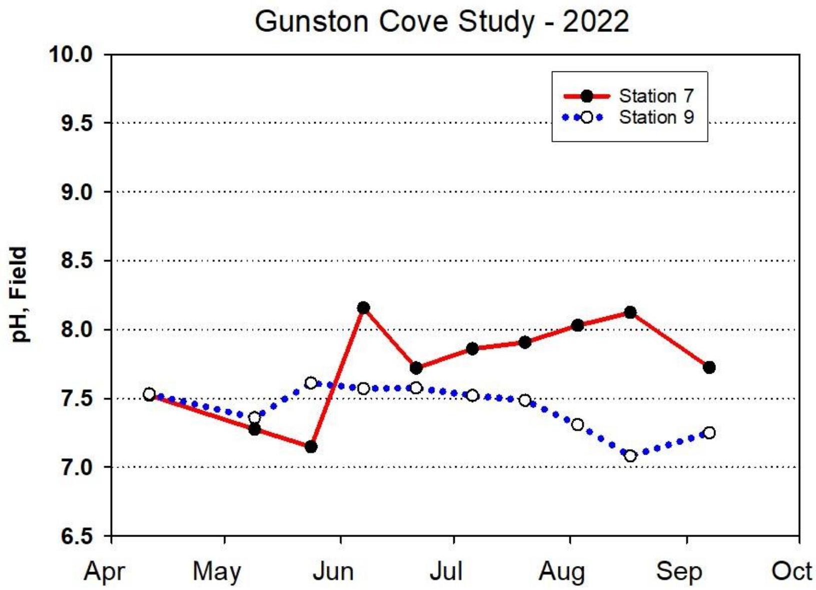


Figure 13. Dissolved Oxygen (% saturation) observed in transects across Gunston Cove during data mapping cruise on August 3, 2022.



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

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

During the summer and into the fall, 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 consistent with a photosynthetic activity effect, probably due to SAV since the high values were observed in shallow water near the shoreline where SAV are most abundant..

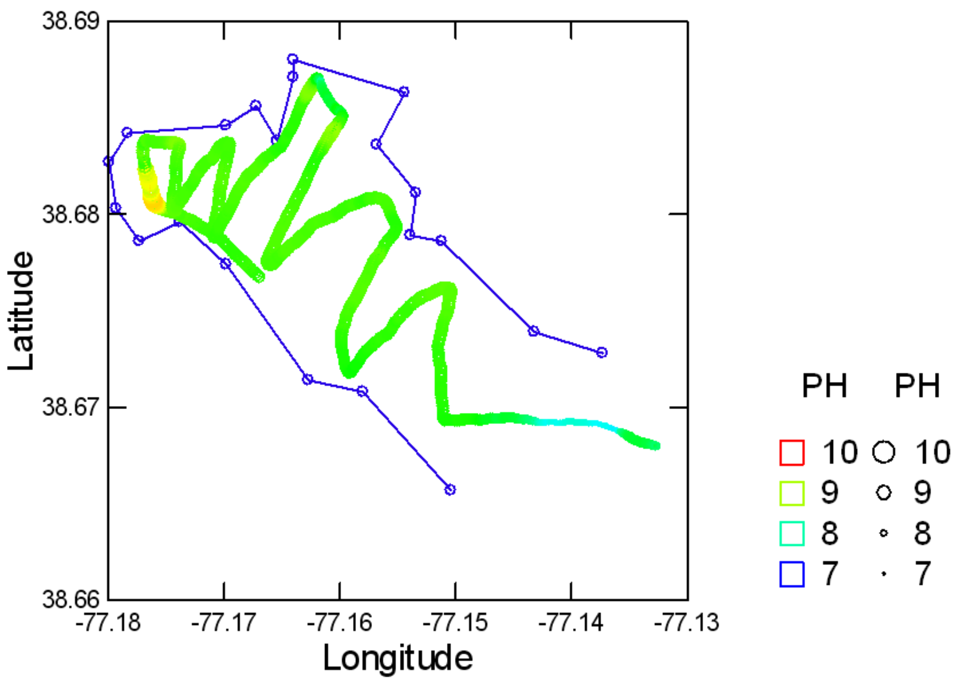
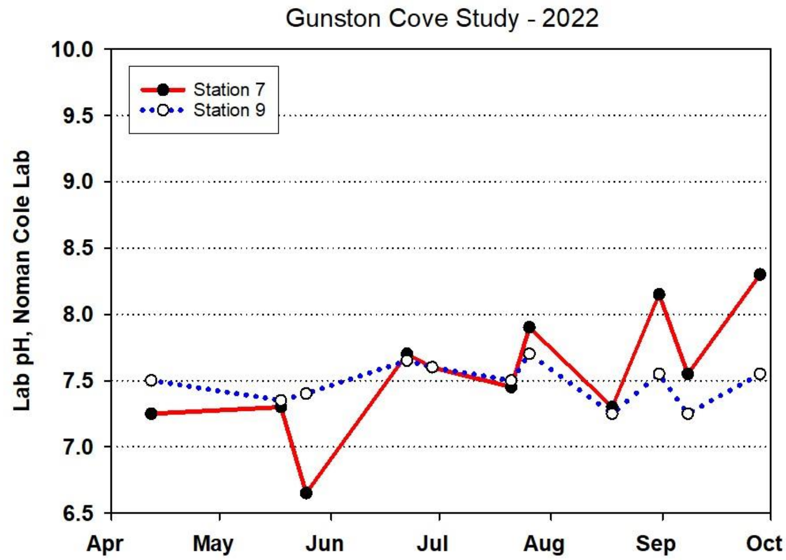


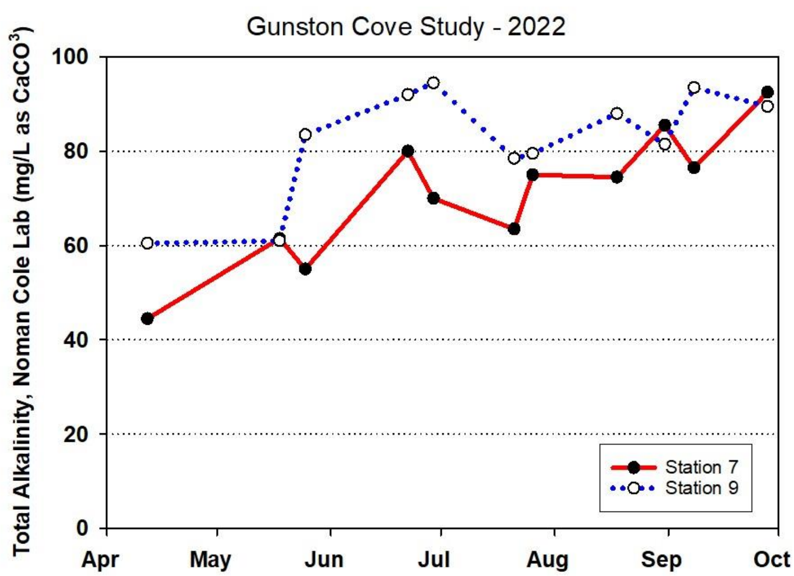
Figure 15. Field pH observed in transects across Gunston Cove during data mapping cruise on August 3, 2022.



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.

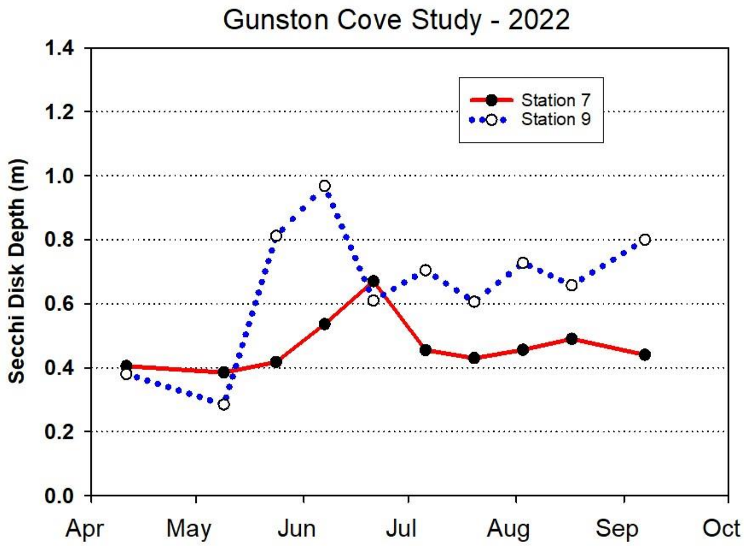
Figure 16. pH. Noman Cole Lab Data. Month tick is at first day of month.

Lab pH was collected less frequently and showed generally similar values between the two stations (Figure 16). Total alkalinity was consistently higher in the river than in the cove by up to 25 mg/L (Figure 17) and showed a generally increasing trend over the period.



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.

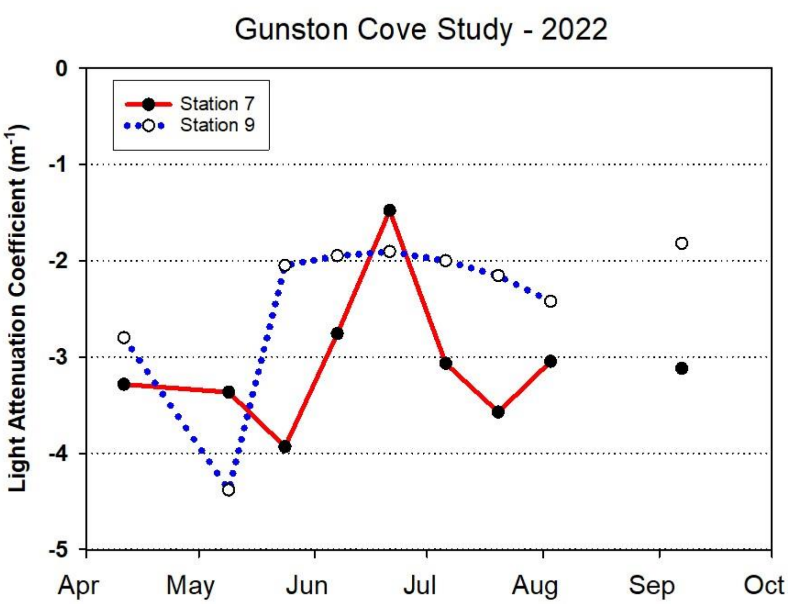
Figure 17. Total Alkalinity (mg/L as $CaCO_3$). Fairfax County Lab data. Month tick is at first day of month.



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

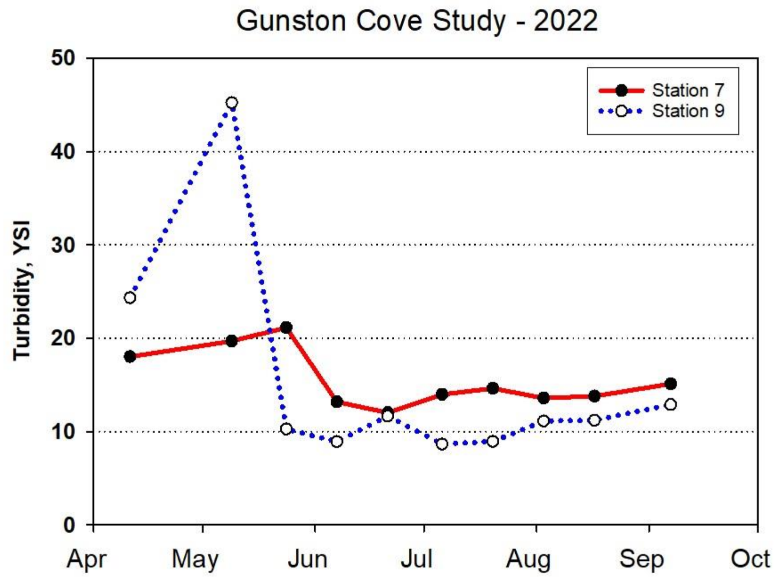
Figure 18. Secchi Disk Depth (m). GMU Field Data. Month tick is at first day of month.

Water clarity as reflected by Secchi disk transparency was quite constant in the cove with values generally between 0.4 m except for June when the water was somewhat more transparent. In the river values were generally somewhat higher with values approaching 1.0 m in early June (Figure 18). Light attenuation coefficient exhibited similar spatial and temporal patterns (Figure 19).



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

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



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

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

Turbidity was fairly constant in the cove and in the river over the study period except in the river in early spring (Figure 20). A very large peak was observed in early May in the river. In the September data mapping cruise, turbidity was generally low except in Pohick Bay where it was somewhat higher, perhaps due to sediment resuspension during the cruise (Figure 21).

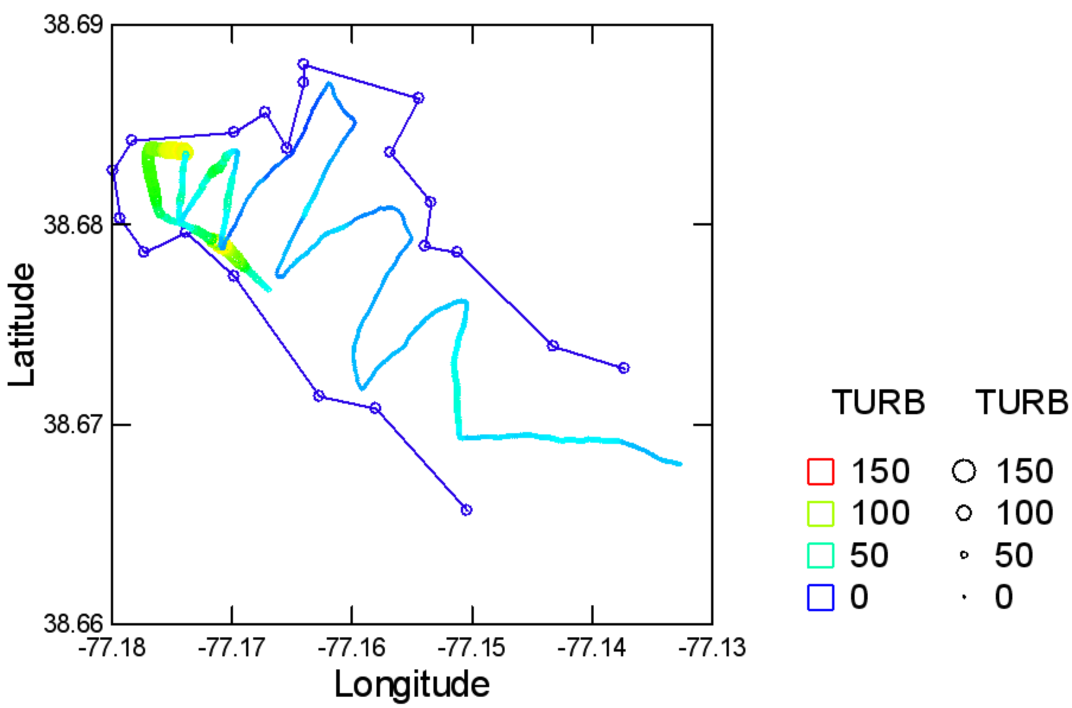
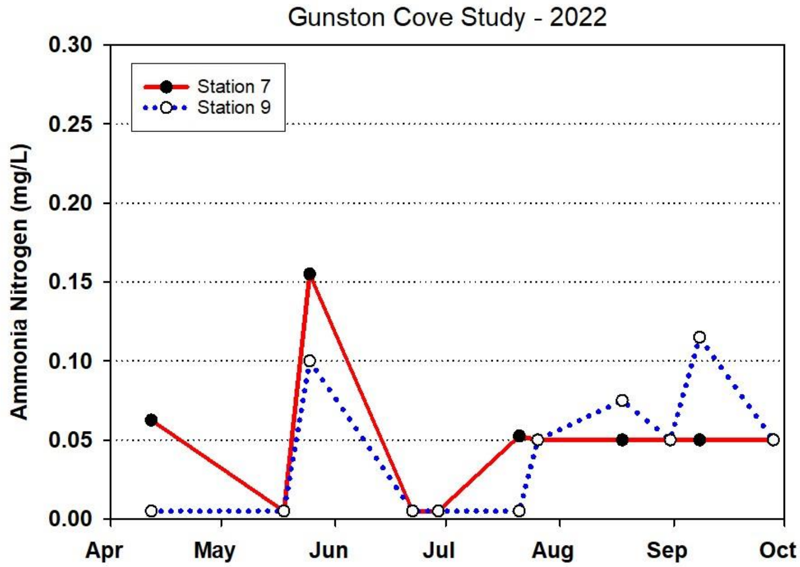


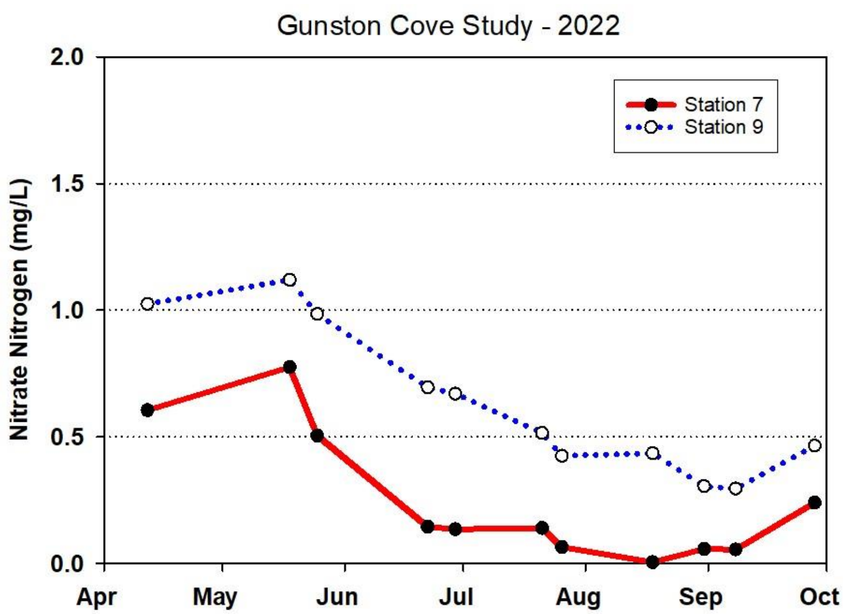
Figure 21. Turbidity (NTU) observed in transects across Gunston Cove during data mapping cruise on August 3, 2022.



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.

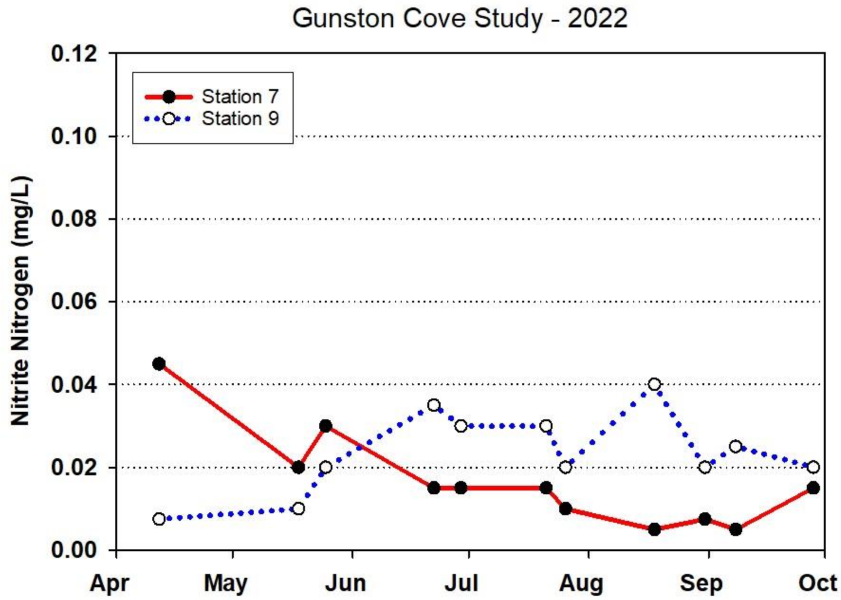
Figure 22. Ammonia Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection: 0.10 mg/L, LD values graphed as 0.05 mg/L)

Ammonia nitrogen was below detection limits in almost all samples reported in 2022 (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. As we pointed out in the 2019 report, this has made it impossible to detect any further improvements in ammonia levels. Nitrate nitrogen levels were consistently higher in the river than in the cove (Figure 23). A clear seasonal decline was observed at both stations, with values at the limit of detection in late August in the cove.



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.

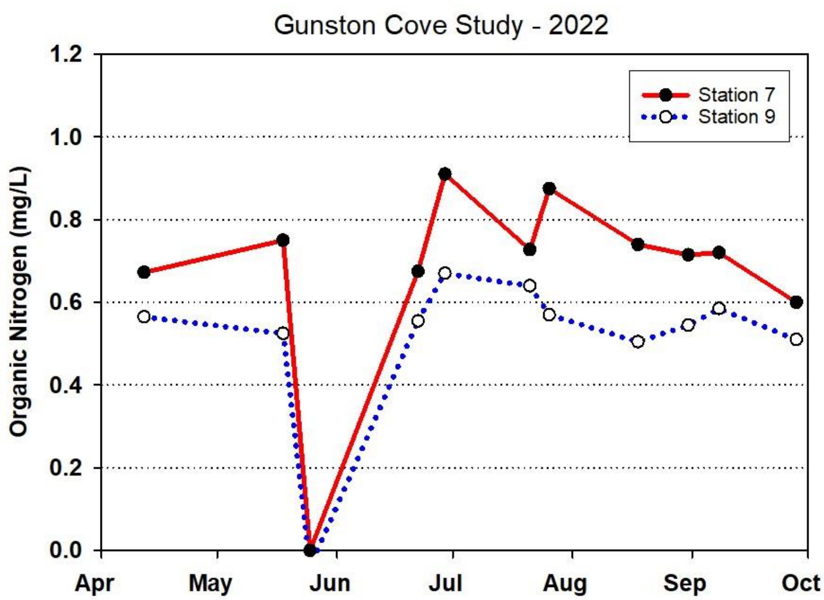
Figure 23. Nitrate Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection: 0.01 mg/L; LD values graphed as 0.005 mg/L)



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.

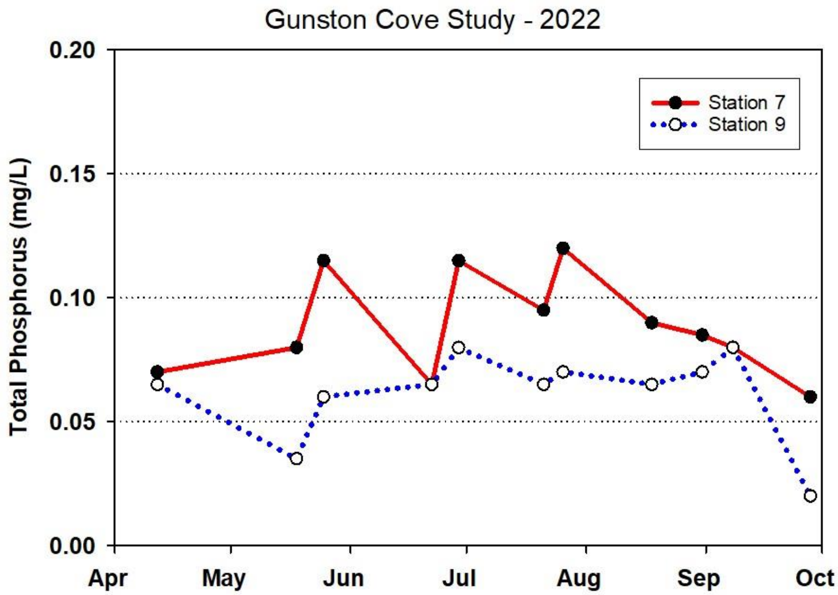
Figure 24. Nitrite Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (limit of detection = 0.01 mg/L).

Nitrite nitrogen was generally low and fairly constant, but was consistently slightly higher in the river (Figure 24). Organic nitrogen was consistently slightly higher in cove than the river (Figure 25). Values were generally consistent over time except for a downward spike in late May at both stations.



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.

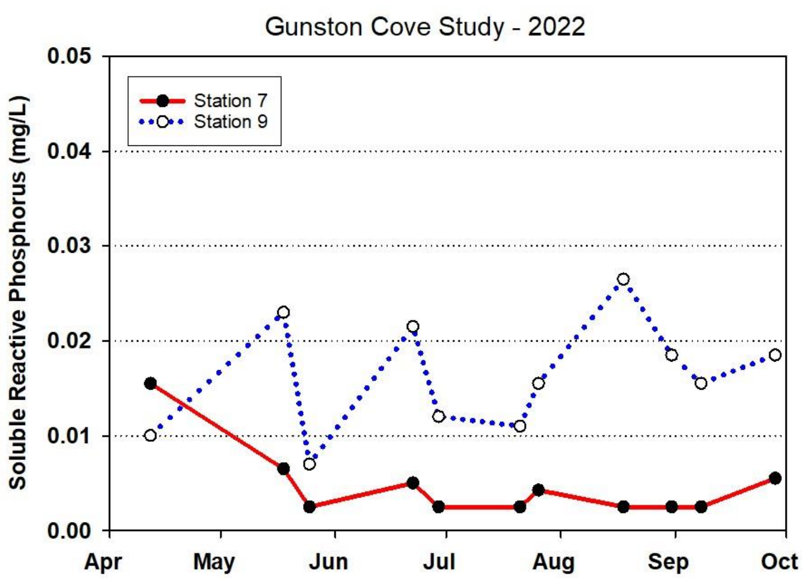
Figure 25. Organic Nitrogen (mg/L). Fairfax County Lab Data. Month tick is at first day of month.



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.

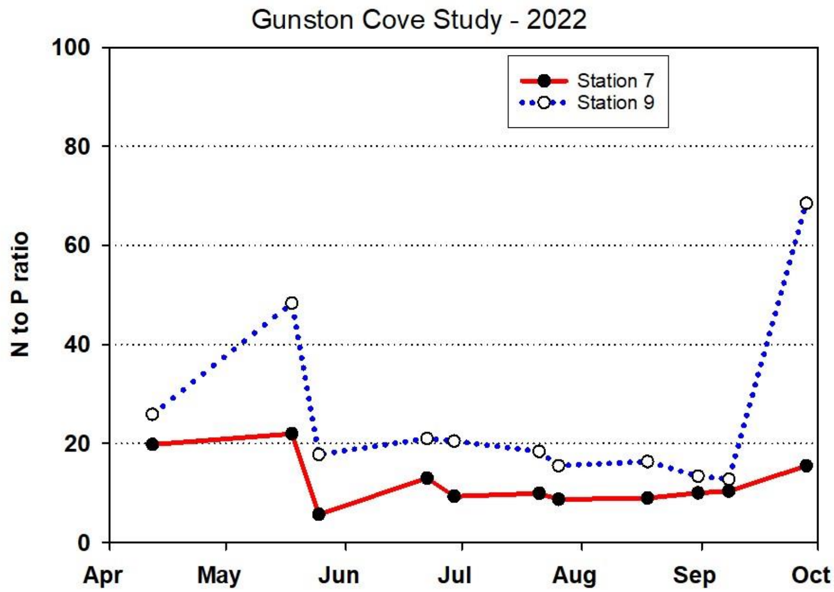
Figure 26. Total Phosphorus (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection: 0.03 mg/L)

Total phosphorus was consistently higher at Station 7 than at Station 9, but showed very little trend over time at either station (Figure 26). Soluble reactive phosphorus was generally substantially higher in the river than in the cove, but again not much in the way of a seasonal trend (Figure 27).



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.

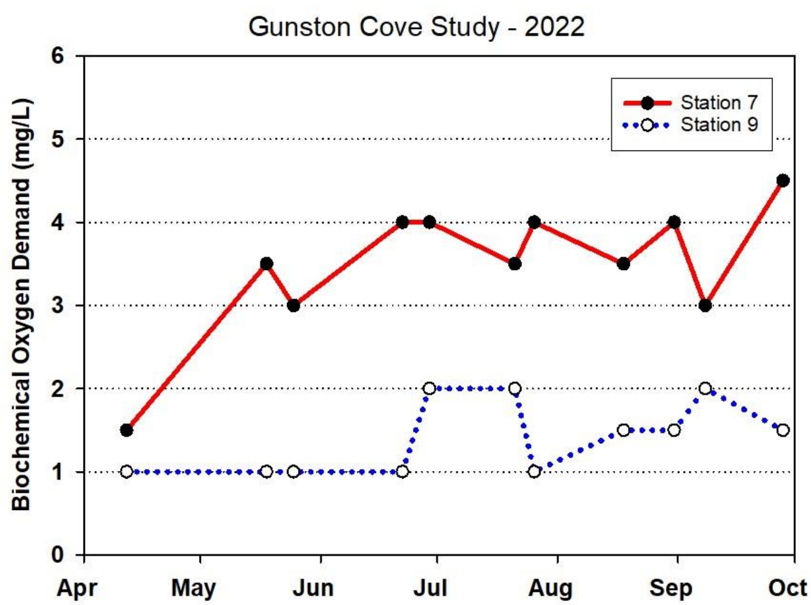
Figure 27. Soluble Reactive Phosphorus (mg/L). Fairfax County Lab Data. Month tick is at first day of month. (Limit of detection = 0.005 mg/L)



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.

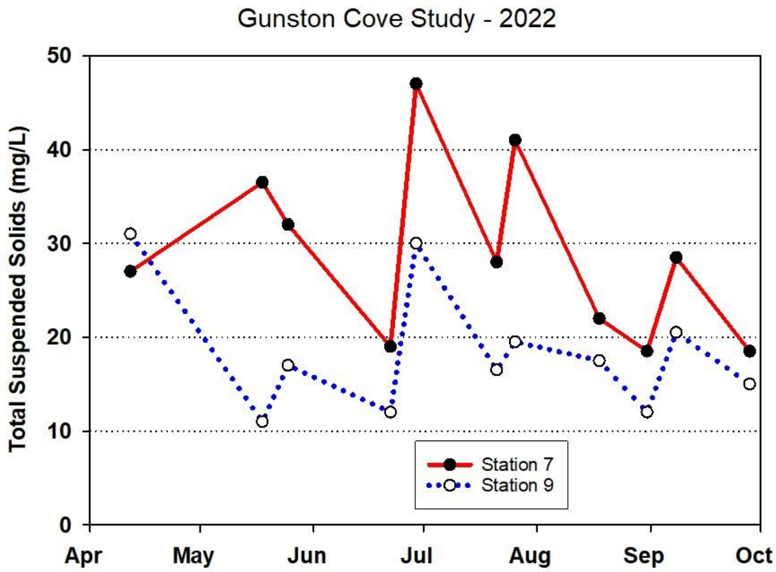
Figure 28. N/P Ratio (by mass). Fairfax County Lab Data. Month tick is at first day of month.

N/P ratio was very constant over the year in Gunston Cove reaching a low of less than 10 in late May and remaining near that value for the rest of the year indicating possible nitrogen limitation. In the river values were slightly higher (near 20) for most of the year, but spiked up occasionally. (Figure 28). Biochemical oxygen demand (BOD) was consistently higher in the cove than in the river and reached a maximum in mid- to late summer (Figure 29).



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

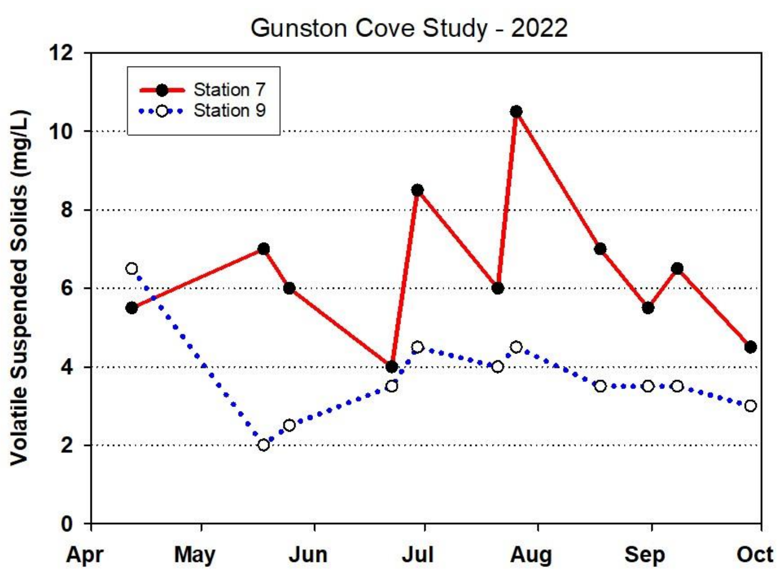
Figure 29. Biochemical Oxygen Demand (mg/L). Fairfax County Lab Data. Month tick is at first day of month.



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.

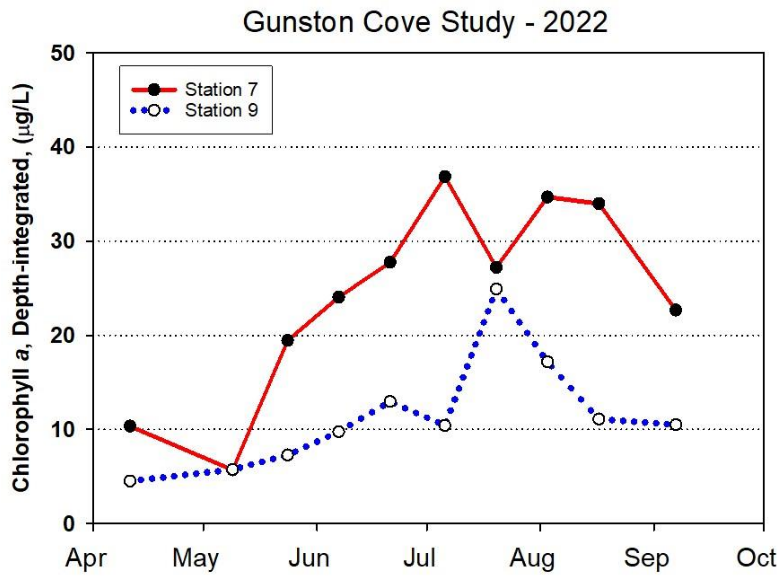
Total suspended solids over the course of the year ranging from 20 to 45 mg/L at Station 7 and 10-30 mg/L at Station 9 (Figure 30). Volatile suspended solids was higher in the cove throughout the year with greatest difference in summer (Figure 31). Values did not show much of a seasonal pattern.



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.

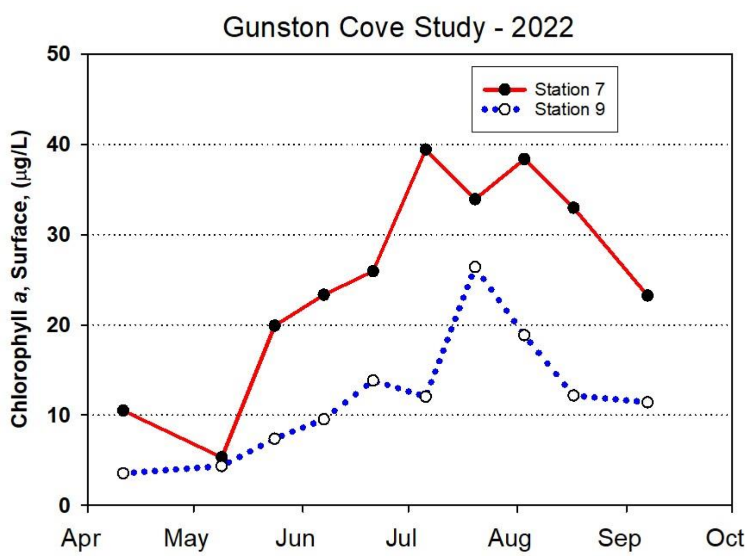
C. Phytoplankton -2022



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. Trilogy soak procedure.

Chlorophyll *a* in the cove grew steadily from early May through early July reaching about 40 µg/L in early July. In the river there was one major peak in late July at about 25 µg/L (Figures 32&33). 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. Trilogy soak procedure.

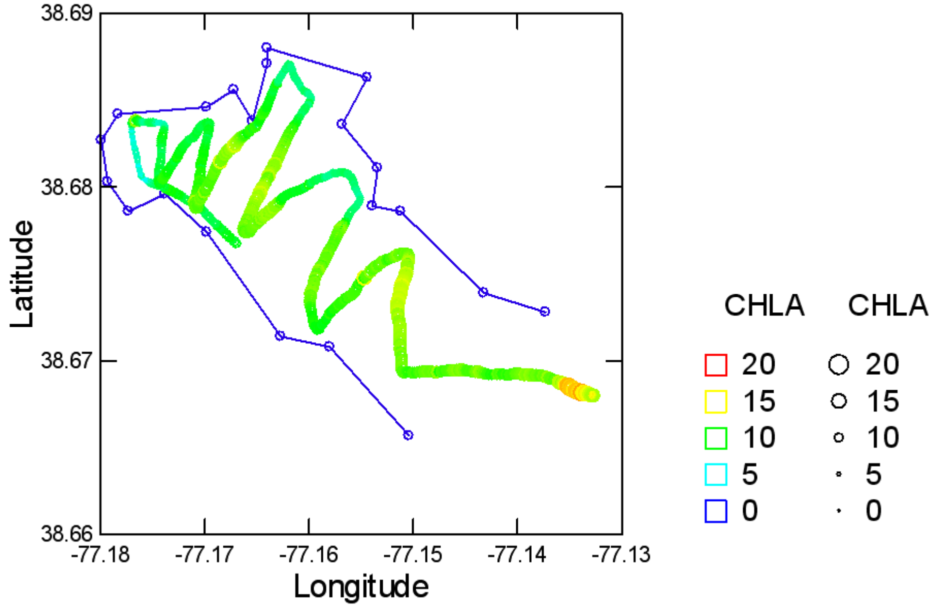


Figure 34. Chlorophyll *a* (µg/L) observed in transects across Gunston Cove during data mapping cruise on August 3, 2022.

Chlorophyll data from the data mapping cruise in 2022 showed a pattern of relatively low values over most of the study area (Figure 34). Lowest values were seen in Pohick and Accotink Bays and highest values near the Potomac mainstem. A graph of dissolved oxygen (an indicator of photosynthesis) vs. phytoplankton chlorophyll showed that high values of DO (>130% saturation) occurred with low levels of phytoplankton (Figure 35). The other potential driver of DO, SAV, was abundant in 2022. SAV depresses phytoplankton chlorophyll. Thus, the high DO values in 2022 can be attributed to both mainly to SAV photosynthesis.

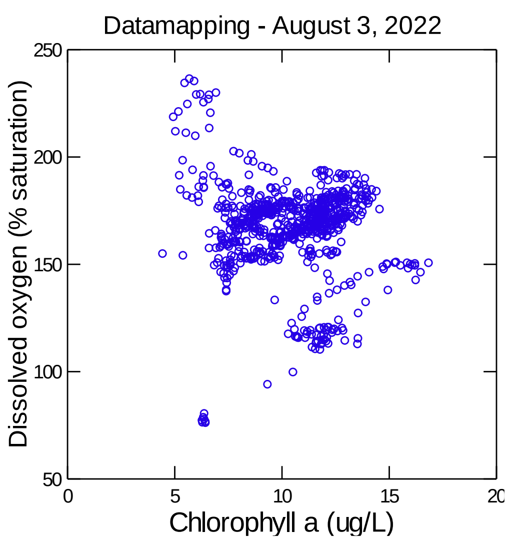
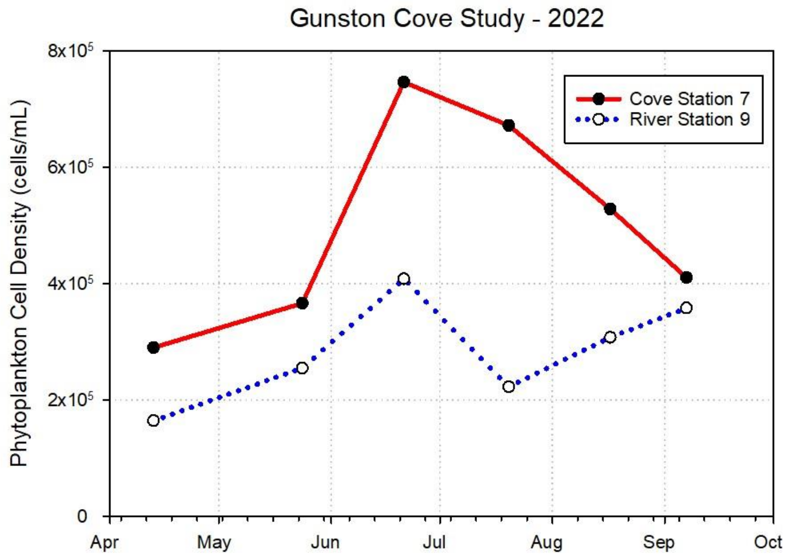


Figure 35. Dissolved Oxygen (% saturation) vs. Chlorophyll *a* (ug/L) as determined by YSI EXO sonde during datamapping on August 3, 2022.



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

Figure 36. Phytoplankton Density (cells/mL)

In the cove phytoplankton density was low in April, then increased to a strong peak in June (Figure 36).. In the river the highest value for phytoplankton density was also observed in June, but at lower values. Biovolume in the river was highest in April and declined throughout the study period. In the cove biovolume was quite variable; the highest value was observed in May and the lowest just one month later in June (Figure 37).

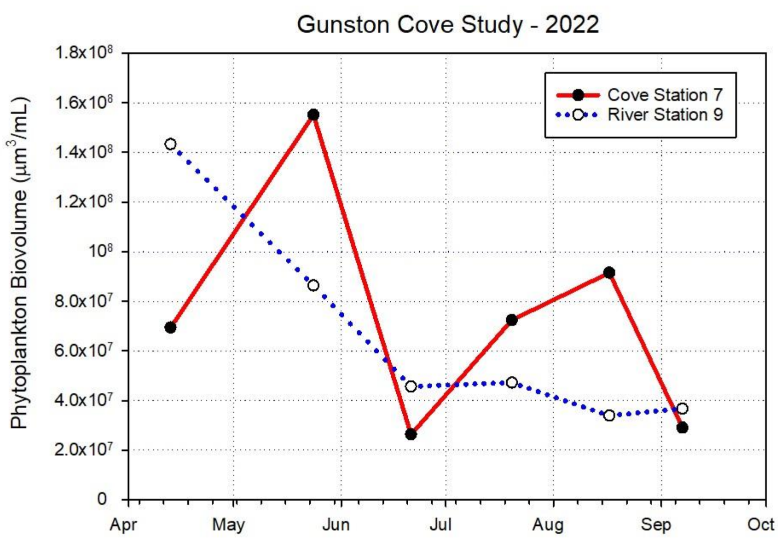
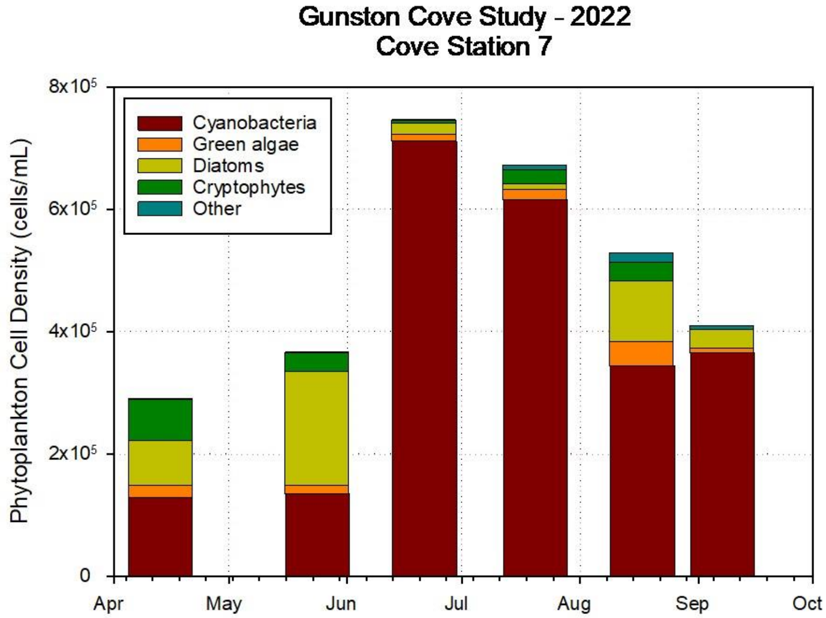


Figure 37. Phytoplankton Biovolume (um^3/mL).

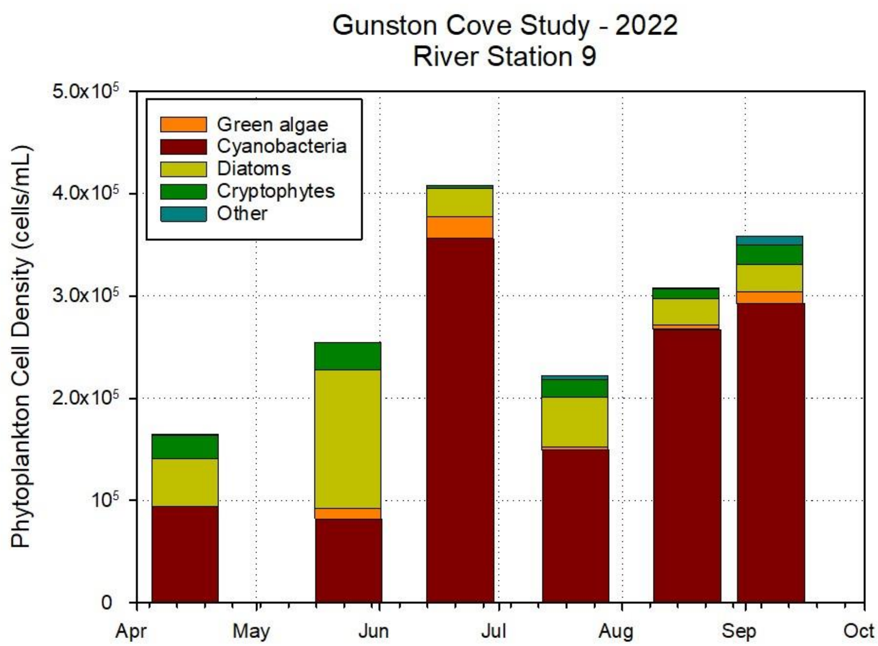
The volume of individual cells of each species is determined by approximating the cells of each species to an appropriate geometric shape (e.g. sphere, cylinder, cone, etc.) and then making the measurements of the appropriate dimensions under the microscope. Total phytoplankton biovolume (shown here)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



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

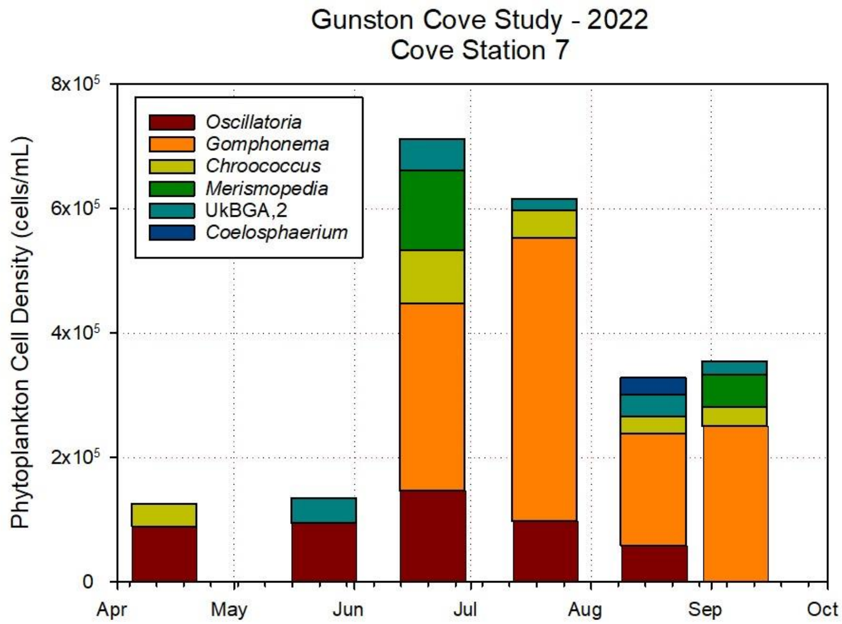
Figure 38. Phytoplankton Density by Major Group (cells/mL). Gunston Cove.

In 2022 phytoplankton density in the cove was dominated by cyanobacteria with diatoms in a secondary role (Figure 38). In the river diatoms dominated in May, but otherwise cyanobacteria were most important (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

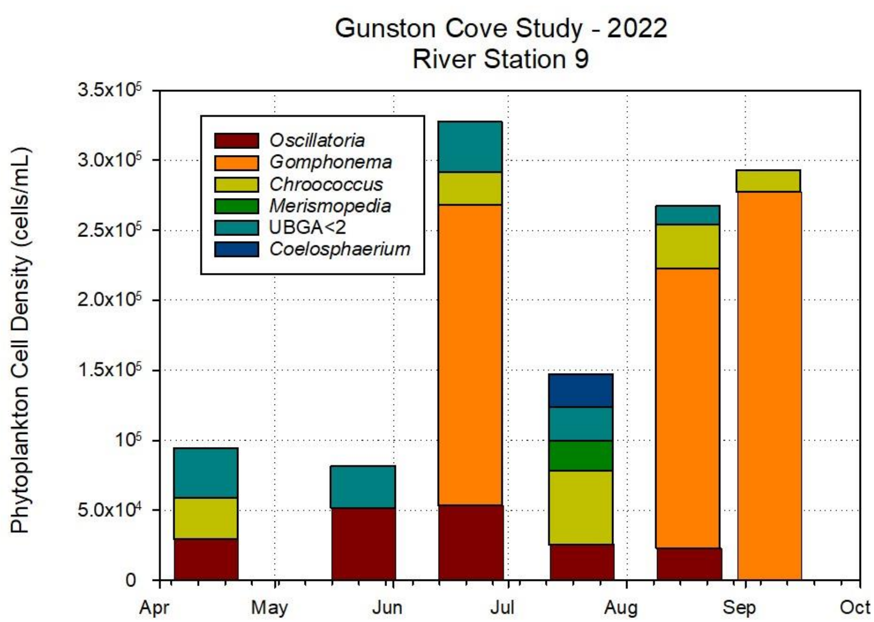
Figure 39. Phytoplankton Density by Major Group (cells/mL). River.



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 maintained a substantial population through most of the year, but *Gomphosphaeria* entered the population in June and dominated for the rest of the year. (Figure 40). In the river a similar pattern was observed (Figure 41).



Anabaena

Microcystis

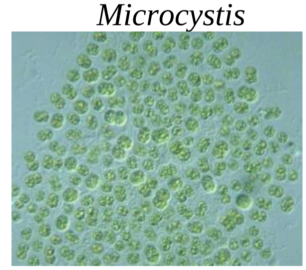
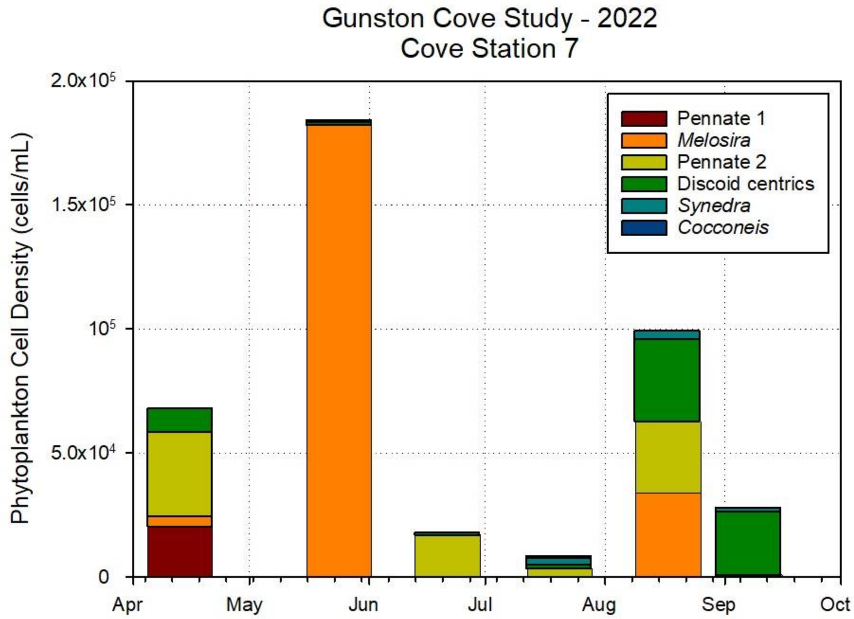


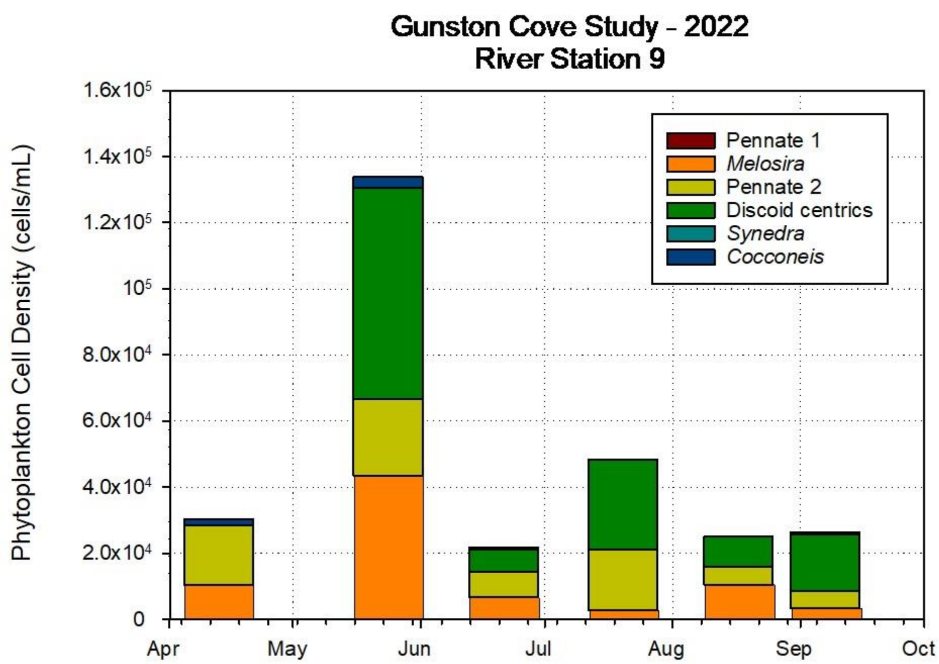
Figure 41. Phytoplankton Density by Dominant Cyanobacteria (cells/mL). River.



The most numerous diatoms in the phytoplankton were:
- *Melosira* – a filamentous centric diatom
- Centrics – discoid centric diatoms
- Pennate 2 – a small pinnate diatom
- *Synedr*a – 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 the cove was dominated by *Melosira* with large numbers in May (Figure 42). In other months, discoid centrics or Pennate 2 were most important. In the river discoid centric diatoms were dominant for most of the year with substantial contributions form Pennate 2 and *Melosira* (Figure 43).



Melosira

Discoid Centrics

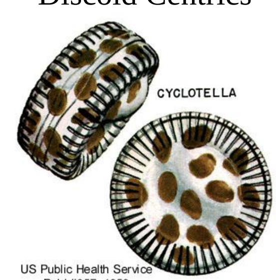
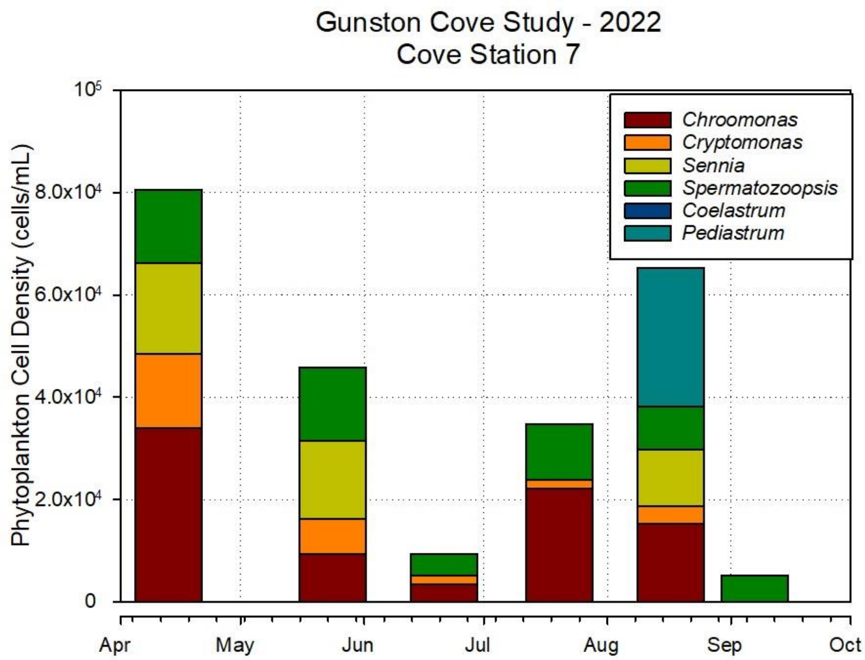


Figure 43. Phytoplankton Density by Dominant Diatoms (cells/mL). River.

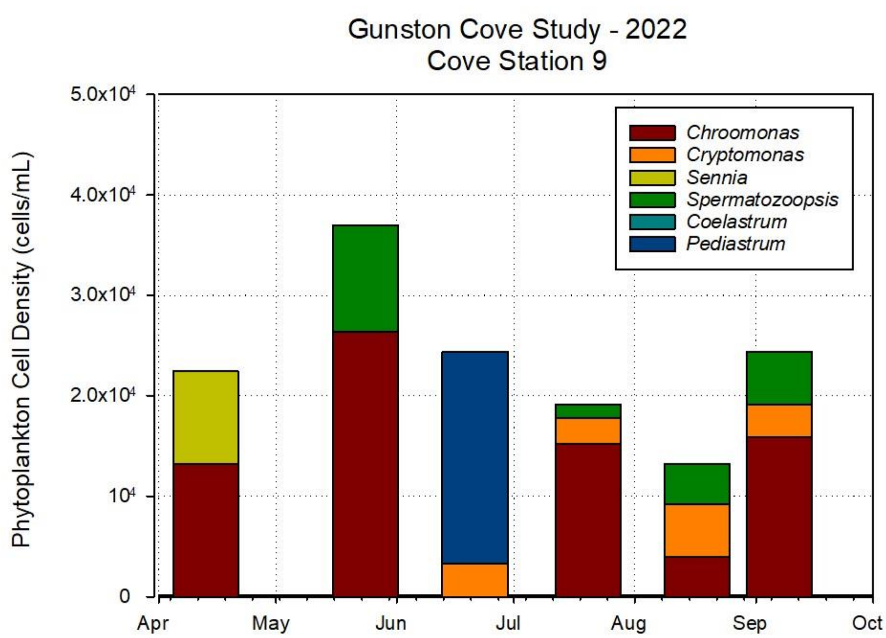


The most numerous phytoplankton among the cryptophytes, green algae and others were:

- *Cryptomonas* – an ellipsoidal, flagellated unicell
- *Chroomonas* – a flagellated cryptomonad unicell
- *Selenastrum* – single green algal cell as curved rod
- *Spermatozoopsis – a flagellated green unicell*
- *Scendesmus – a green alga composed of a 4-celled colony*
- *Ankistrodesmus* – a green alga that is long and thin

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

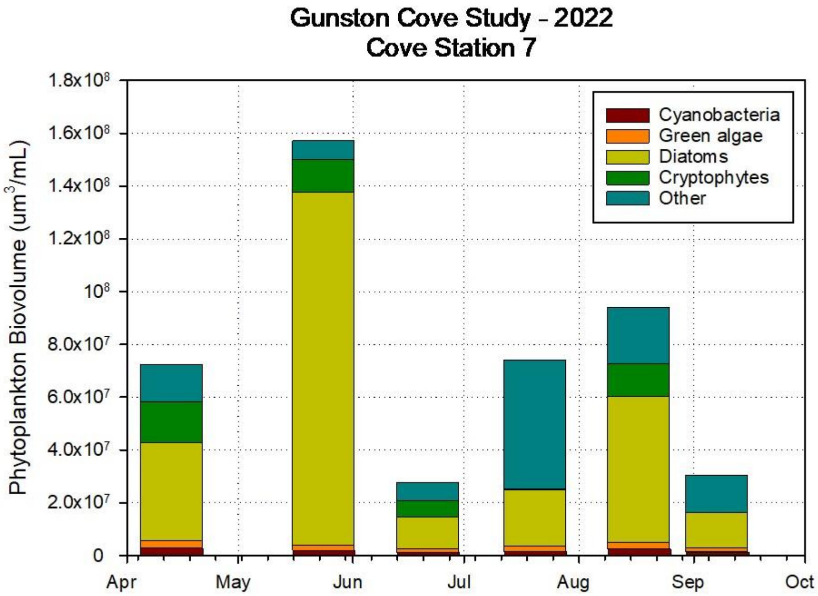
In the cove a number of other taxa were important, with the combination of *Chroomonas* and *Cryptomonas* being present at substantial levels each month except September (Figure 44). The green alga *Pediastrum* was dominant in August. The river station had a similar assemblage with *Chroomonas* and *Cryptomonas* dominant in most month (Figure 45).



Cryptomonas

Scenedesmus

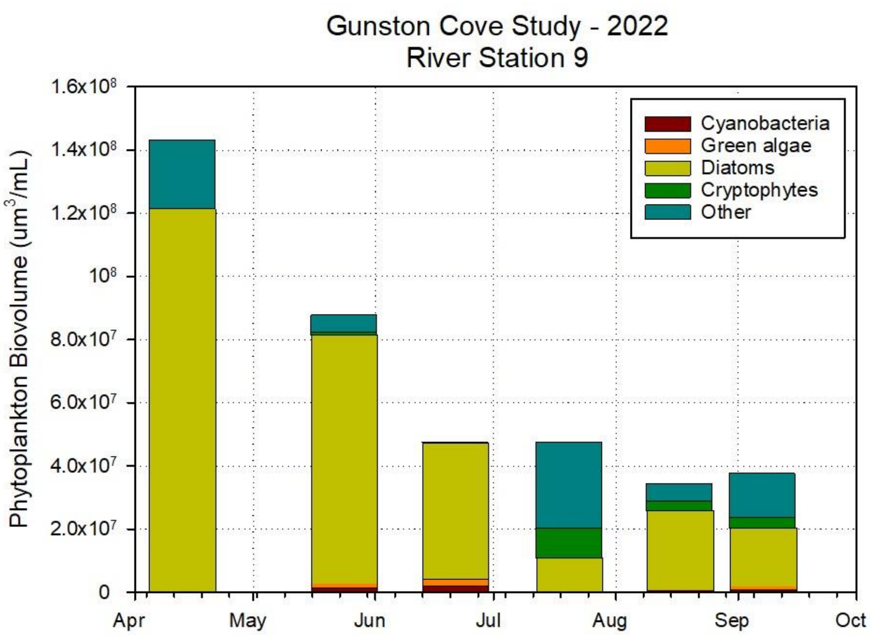
Figure 45. Phytoplankton Density (#/mL) by Dominant Other Taxa. River.



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

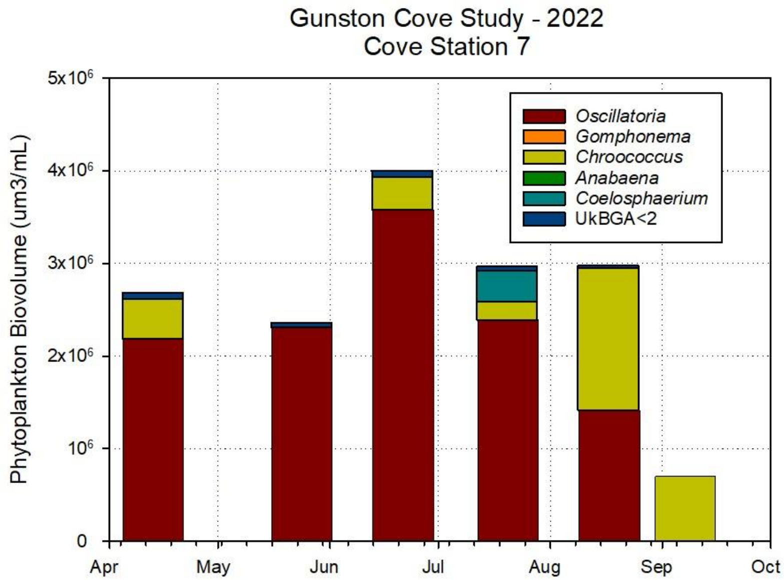
Figure 46. Phytoplankton Biovolume (um^3/mL) by Major Groups. Gunston Cove.

In the cove biovolume was strongly dominated by diatoms through most of the year (Figure 46).. In the river, diatoms were strongly dominant in biovolume most of the year with Other algae being more important in August (Figure 47).



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

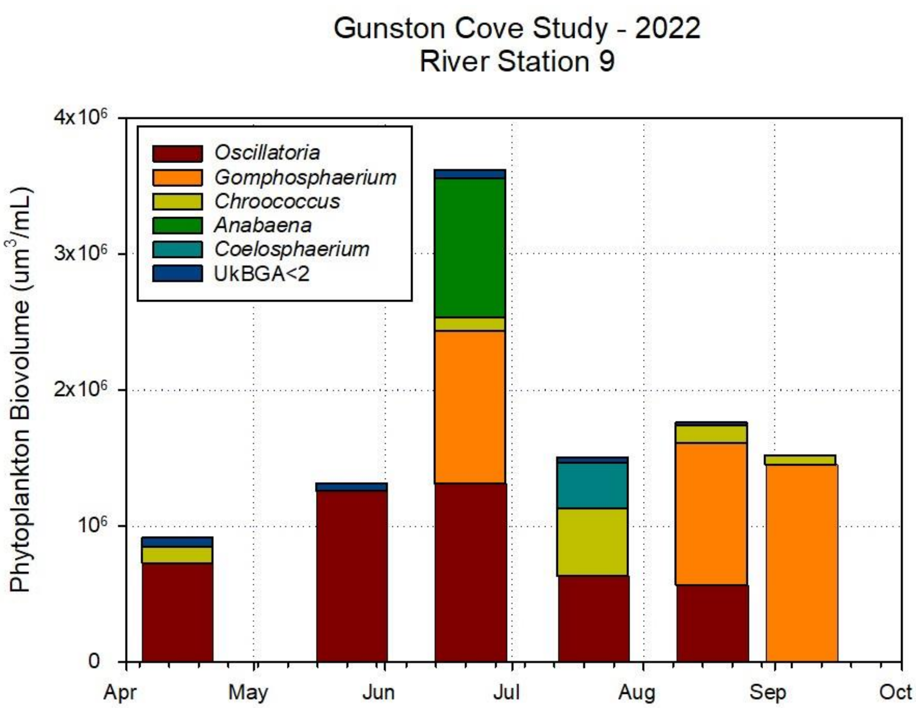
Figure 47. Phytoplankton Biovolume (um^3/mL) by Major Groups. River.



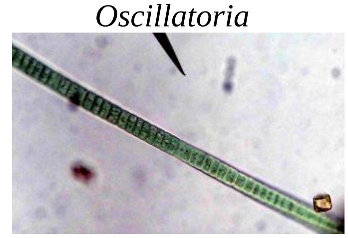
The dominant cyanobacteria on a biovolume basis were:
Anabaena – a filament with bead-like cells & heterocysts
Rhabdoderma – rod-shaped cells in small packets
Oscillatoria – a filament with cylindrical cells
Chroococcus – individual spherical cells
Raphidiopsis – a filament of cylindrical cells

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

Oscillatoria accounted for most of the cyanobacterial biovolume in the cove except in August when *Chroococcus* was slightly more abundant (Figure 48). It reached a maximum in June. In the river *Oscillatoria* was dominant in spring and early summer. Gomphosphaerium was often dominant in the later part of the year (Figure 49).



Oscillatoria



Chroococcus

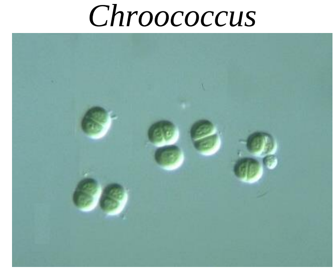
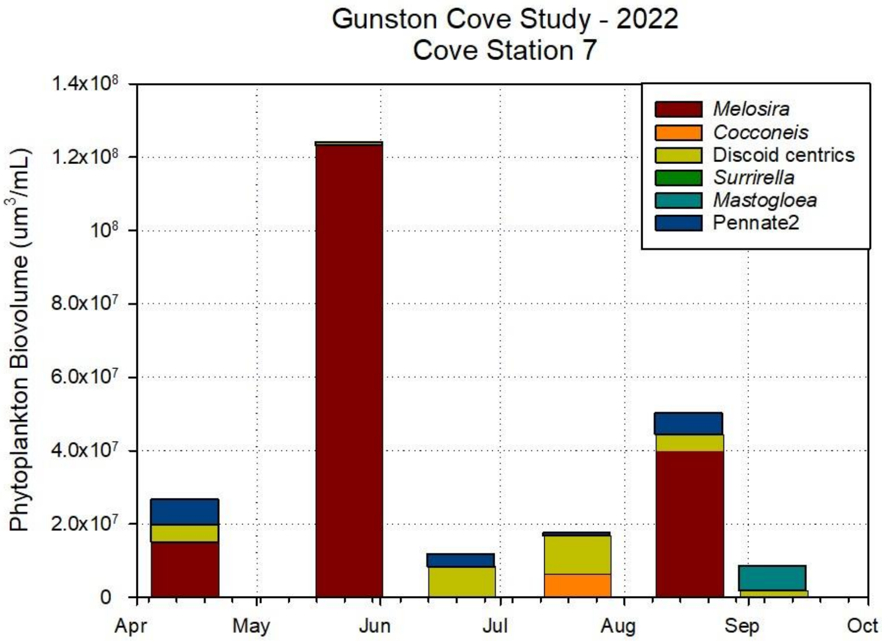


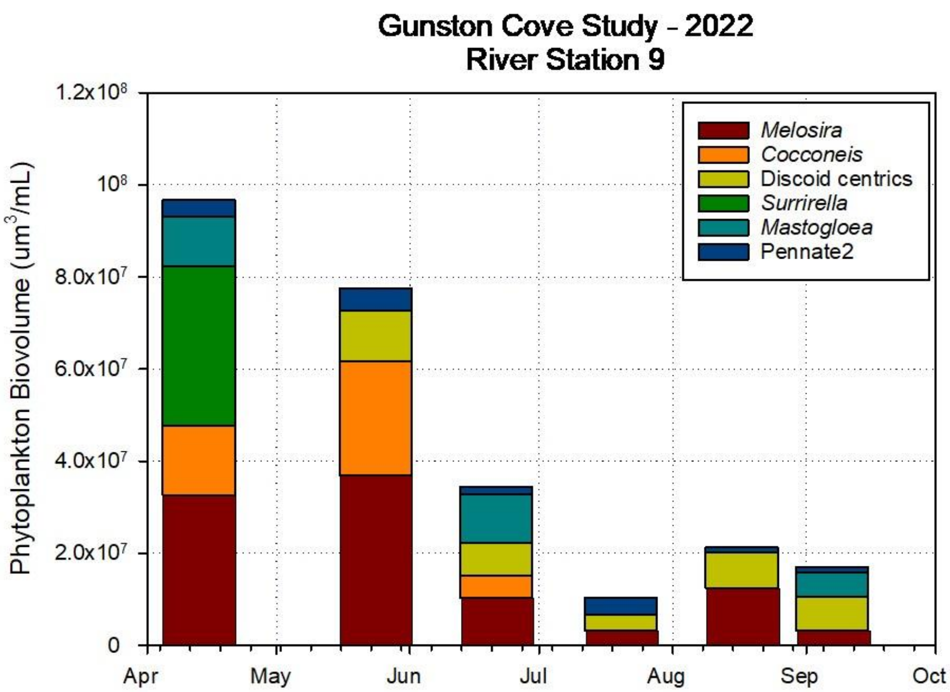
Figure 49. Phytoplankton Biovolume (um^3/mL) by Cyanobacterial Taxa. River.



The most numerous diatoms in the phytoplankton were:
- *Melosira* – a filamentous centric diatom
- Centrics – discoid centric diatoms
- *Stauroneis* – larger pennate diatom
- Pennate 2 – a small pinnate diatom
- Pennate 1 – a small pinnate diatom
- *Surirella* – a larger pennate diatom
- *Nitzschia* – a small pennate diatom

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

In the cove *Melosira* was dominant and very abundant in May (Figure 50). Discoid centrics were most important in July and August. in September. In the river Melosira was generally the most important, but shared dominance with Surriella or Cocconeis in spring (Figure 51).



Melosira

Surirella

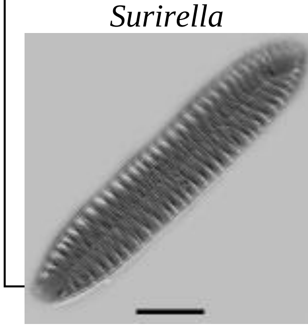
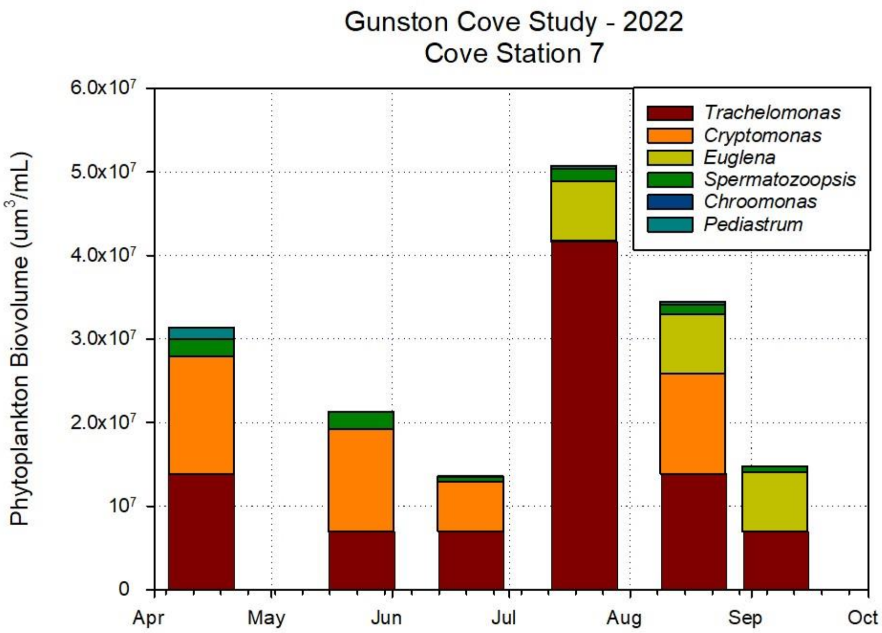


Figure 51. Phytoplankton Biovolume (um^3/mL) by Diatom Taxa. River.

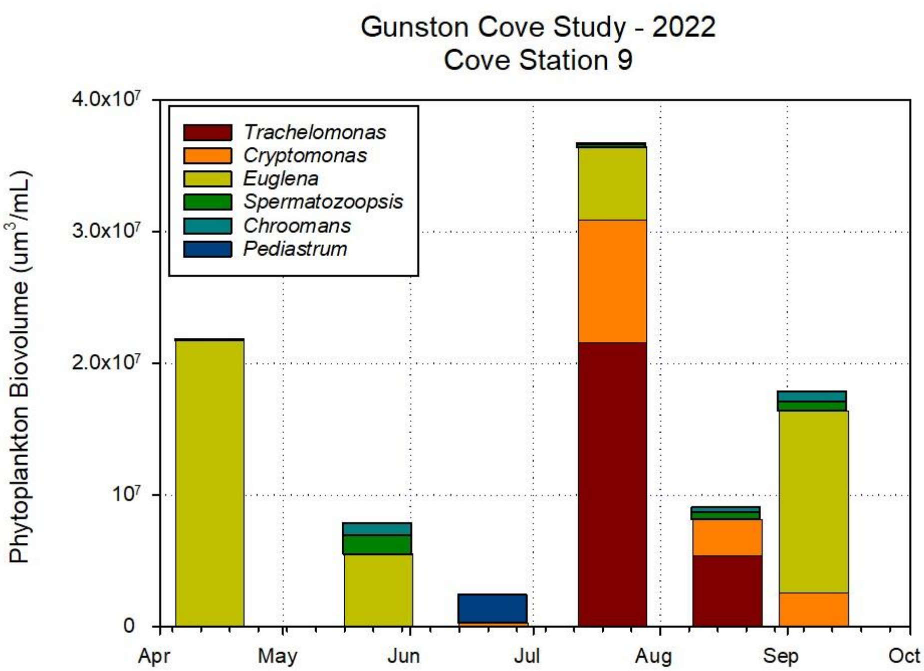


The most numerous phyto-plankton among the cryptophytes, green algae and others were:

- *Euglena* – large euglenoid flagellate
- *Cryptomonas* – an ellipsoidal, flagellated unicell
- *Carteria* – flagellated green unicell
- *Mallomonas* – unicellular scaled flagellate
- *Trachelomonas* – spherical, armored euglenoid
- *Ankistrodesmus* – rod-like single celled green alga
- *Oocystis* –green unicells in small packets

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

A number of other taxa contributed to biovolume in the cove in 2022 with *Cryptomonas* and *Trachelomonas* being dominant in most months (Figure 52). *Euglena* was important from June through September. In the river the *Euglena* was abundant for most of the year and shared dominance with *Trachelomonas* in July and August (Figure 53).



Cryptomonas

Euglena

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

D. Zooplankton – 2022

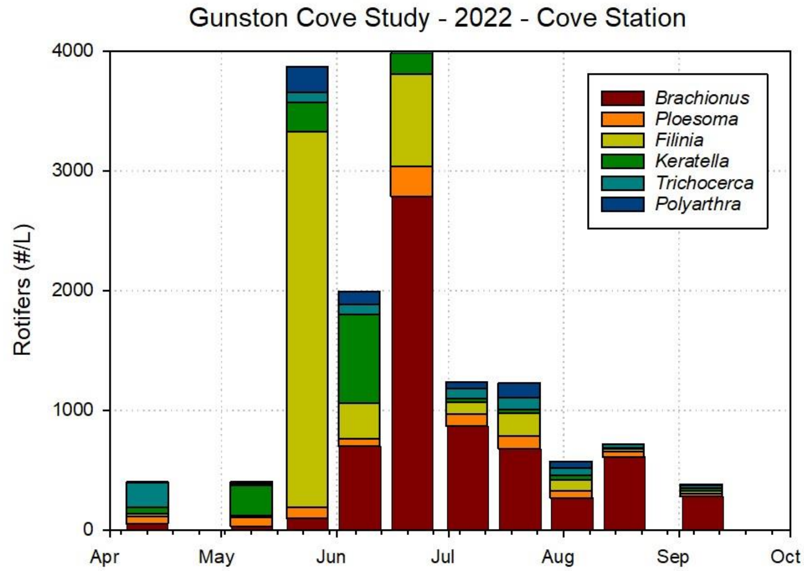
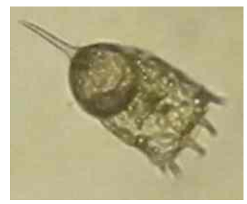


Figure 54. Rotifer Density by Dominant Taxa (#/L). Cove.

Brachionus (Sta 7, RCJ)



Keratella (Sta 7, RCJ)

In the cove, rotifers reached two peaks in 2022, both reaching nearly 4000/L. One in late May was dominated by *Filinia* and a second in late June was dominated by *Brachionus* (Figure 54). In the river rotifers were consistently substantially lower than in the cove with the highest value in early June of about 1100/L (Figure 55). *Brachionus* was the dominant in most samples.

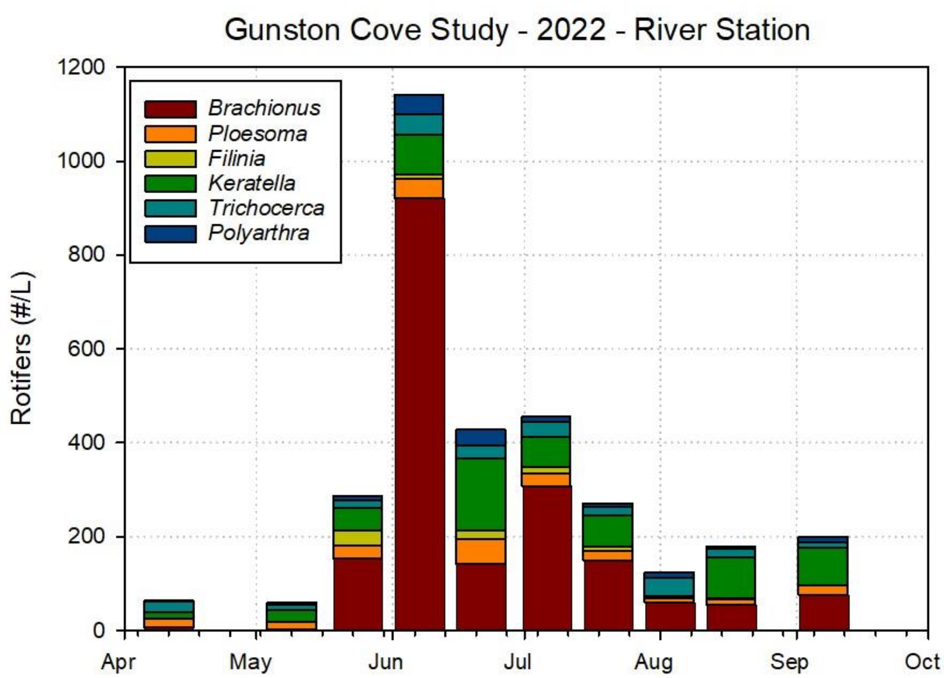
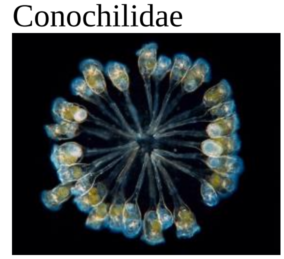


Figure 55. Rotifer Density by Dominant Taxa (#/L). River.

Brachionus (c. 50 um)

Conochilidae



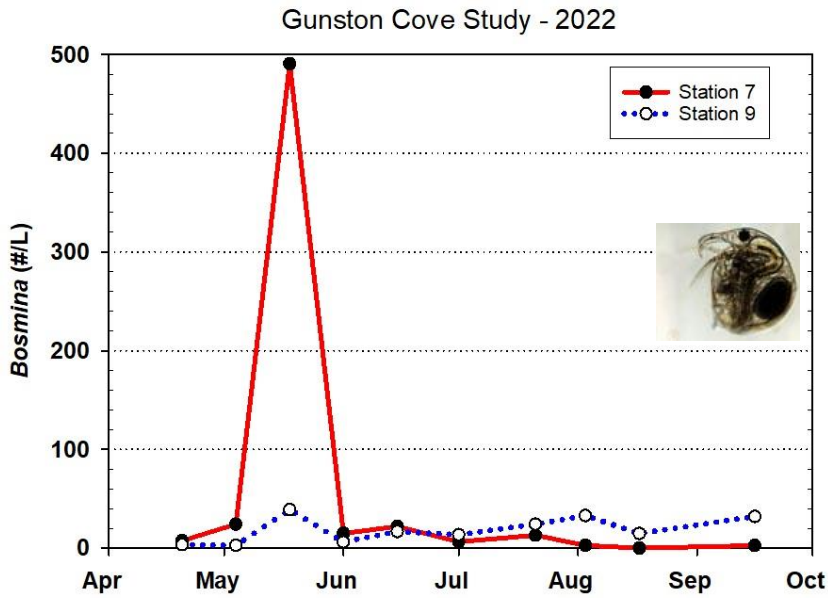


Figure 56. *Bosmina* Density by Station (#/L).

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

In 2022 the small cladoceran *Bosmina* exhibited a major peak in the cove at nearly 500/L in late May (Figure 56). *Bosmina* was much scarcer in the river in 2022, never more than 50/L. *Diaphanosoma,* typically the most abundant larger cladoceran in the study area, was quite abundant in the river and cove in 2022. In the cove it peaked in early June at about 1000/m^3 (Figure 57). Two peaks were observed at the river station at about the same level: one in early June and one in late July

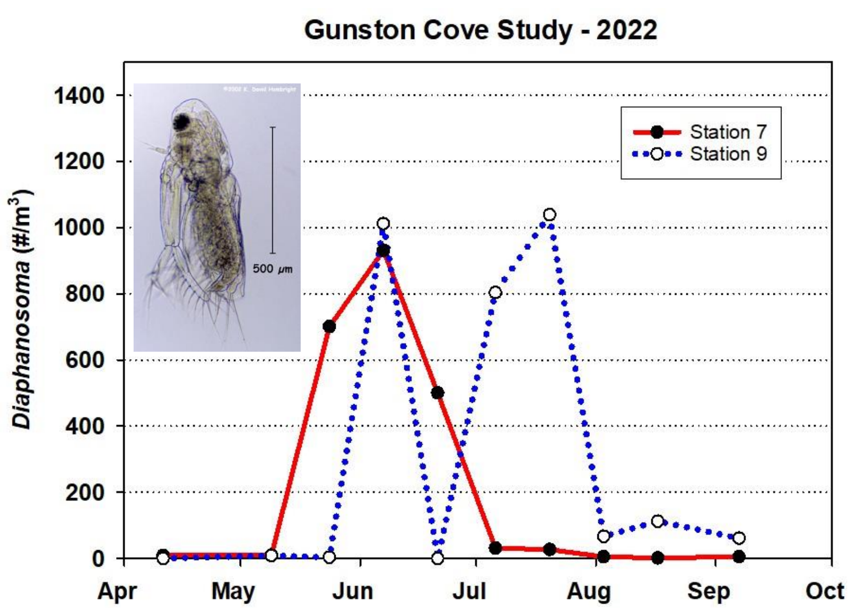
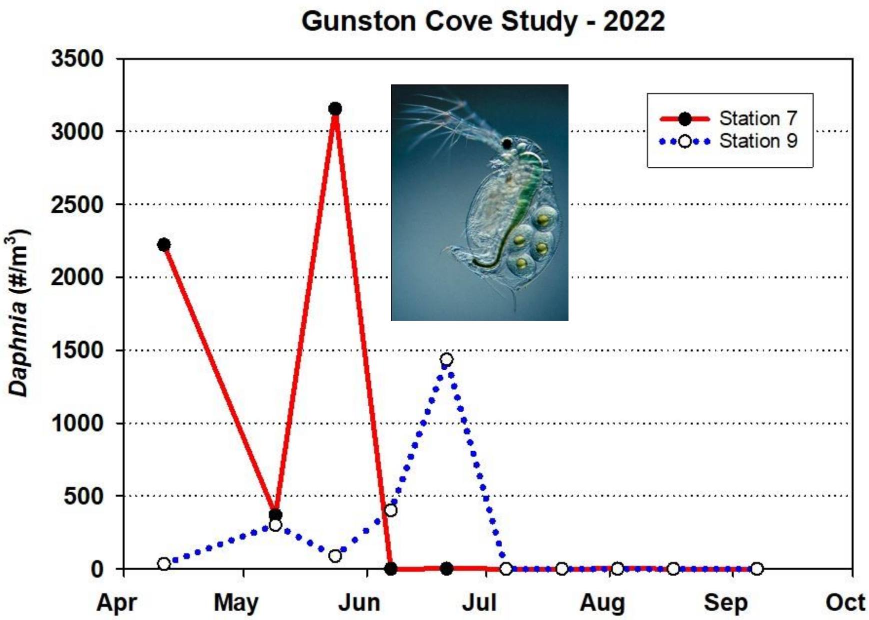


Figure 57. *Diaphanosoma* Density by Station (#/m^3).

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



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

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

In 2022 *Daphnia* exhibited two major peaks in the cove: one in April at about 2200/m^3 and one in late May at about 3200/m^3 (Figure 58). These are among the highest levels ever observed for *Daphnia* in the Gunston Cove Study. In the river the maximum was about 1500/m^3 in late June. *Ceriodaphnia* was present at only low levels in 2022 (Figure 59).

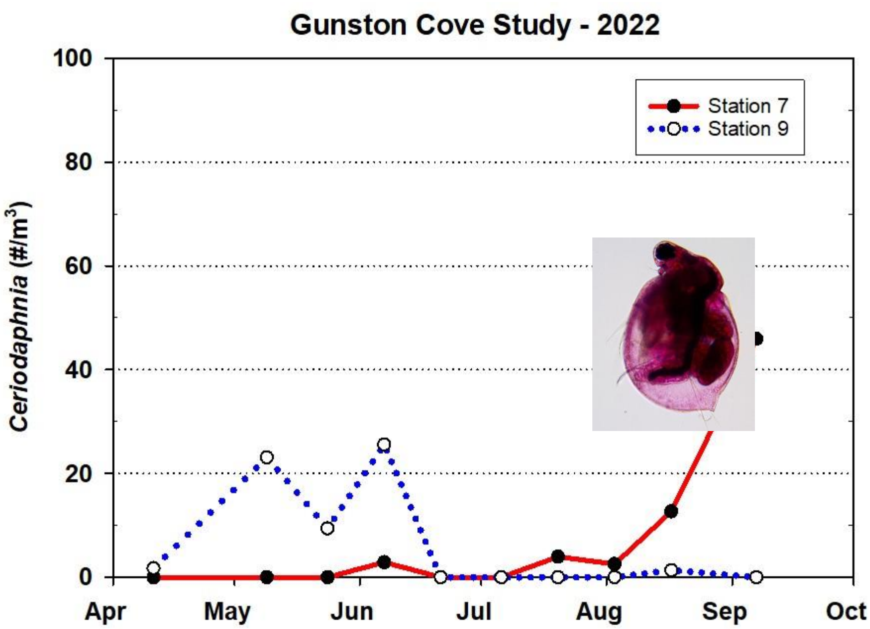
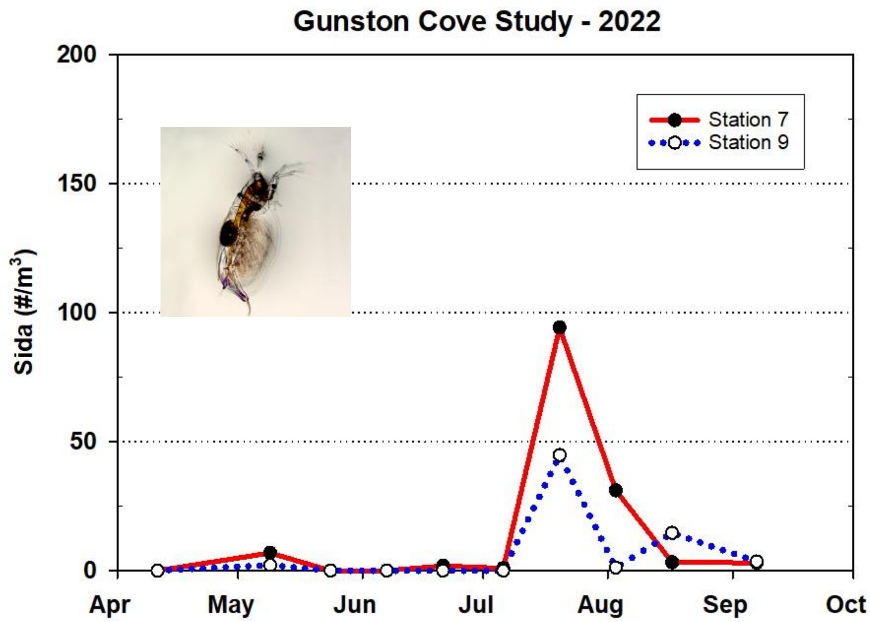


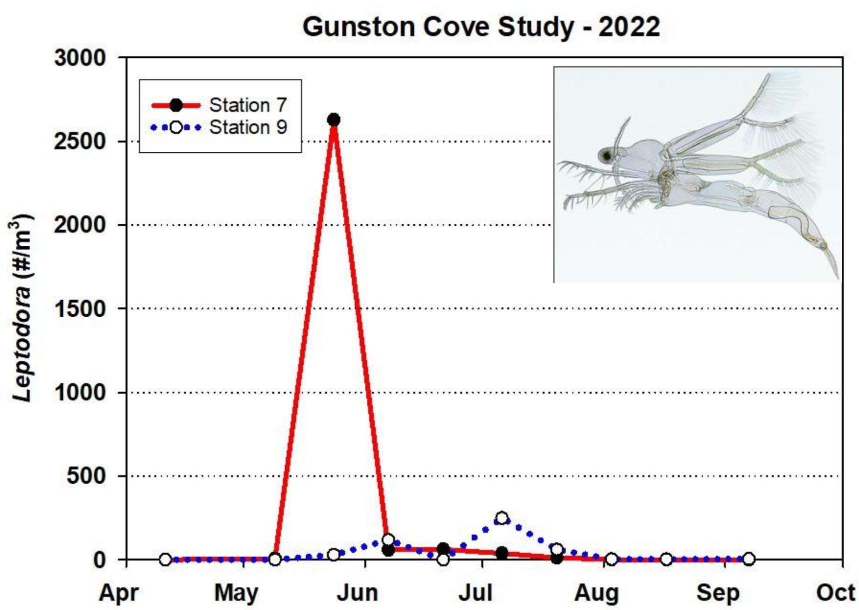
Figure 59. *Ceriodaphnia* Density by Station (#/m^3).



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.

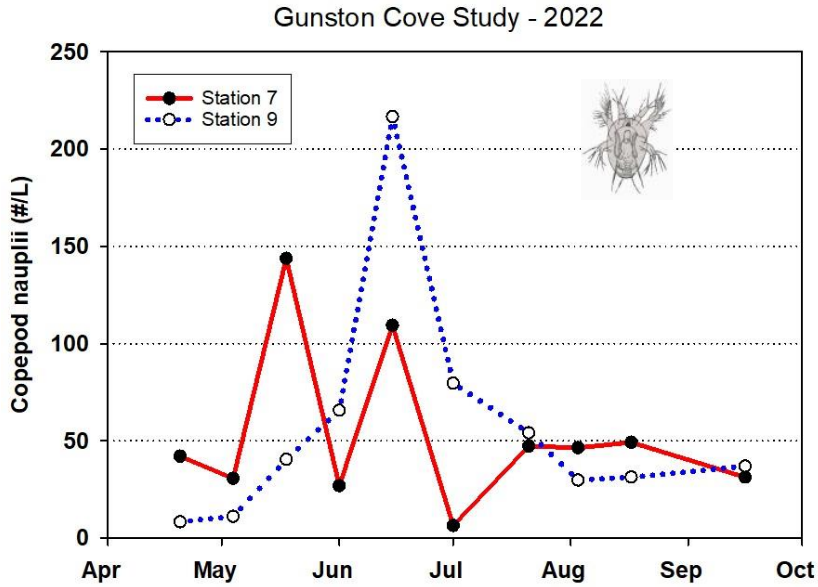
Figure 60. *Sida* Density by Station (#/m^3).

Sida, a smallish cladoceran related to *Diaphanosoma*, was present at relatively low levels for most of the year, reaching a peak of about 100/m^3 in late July in the cove (Figure 60). *Leptodora*, the large cladoceran predator, was quite abundant in in mid-May reaching a peak of over 2500/m^3 in the cove. It didn't exceed 200/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.

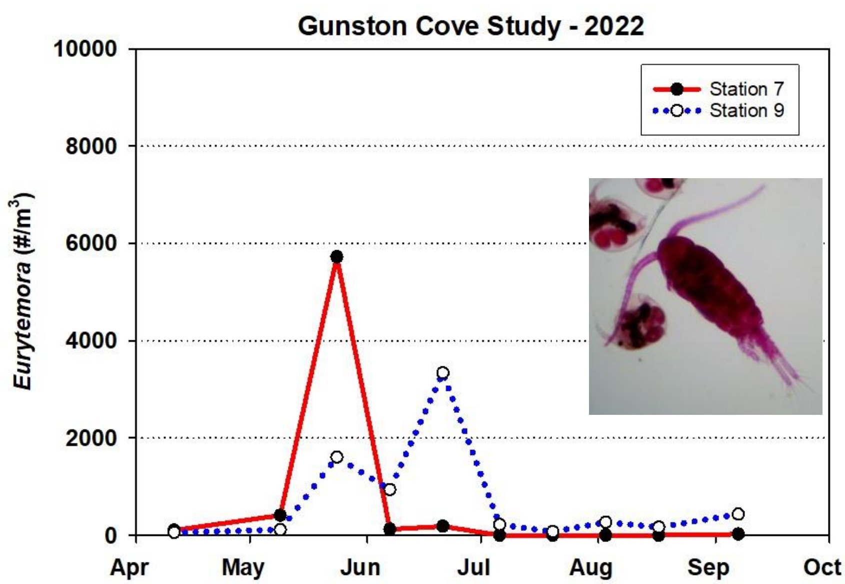
Figure 61. *Leptodora* Density by Station (#/m^3).



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).

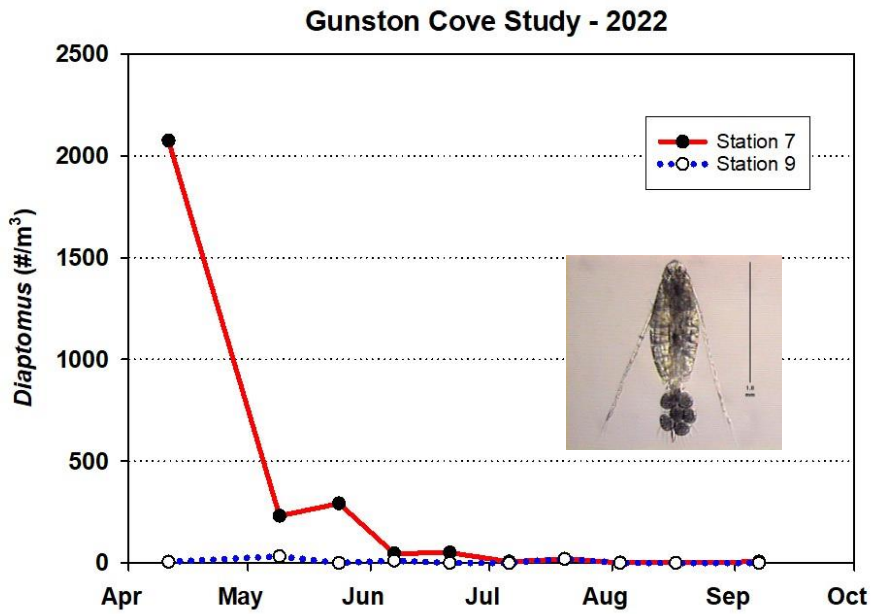
In the river copepod nauplii showed a pattern of major increase over the period from April to June reaching a peak of about 200/L before declining for the rest of the year (Figure 62). In the cove values fluctuated with two spring peaks at lower levels. In 2022 *Eurytemora* attained high densities of nearly 6,000/m^3 in May but for most of the year values were lower than in the river (Figure 63). In the river *Eurytemora* attained about 3000/m^3 in June.



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*.

Photo credit: Laura Birsa

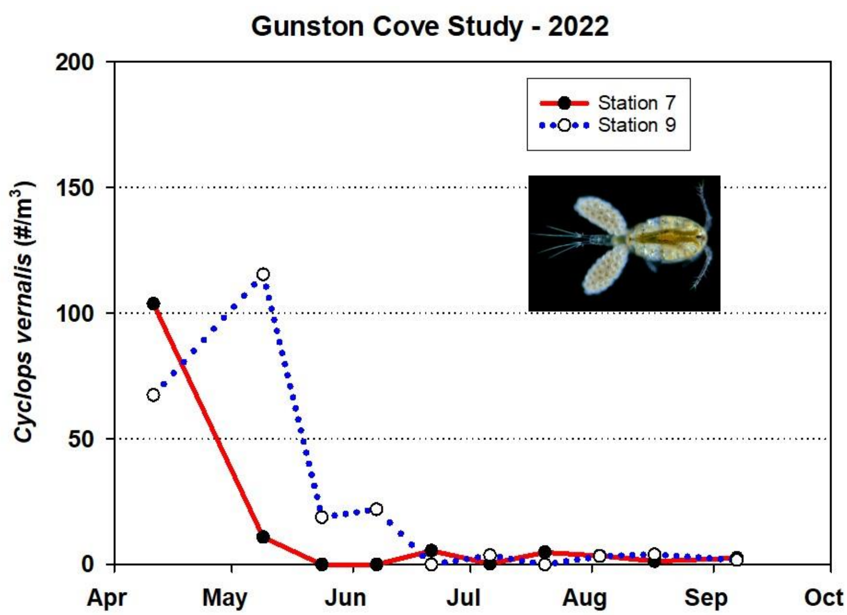
Figure 63. *Eurytemora* Density by Station (#/m^3).



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 most abundant in April of 2023 at a level of 2000/m3 in the cove (Figure 64). Values were low in the river. *Cyclops vernalis* was at low and decreasing values in both the cove and the river in 2022 (Figure 65).



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

Figure 65. *Cyclops vernalis* by Station (#/m^3)..

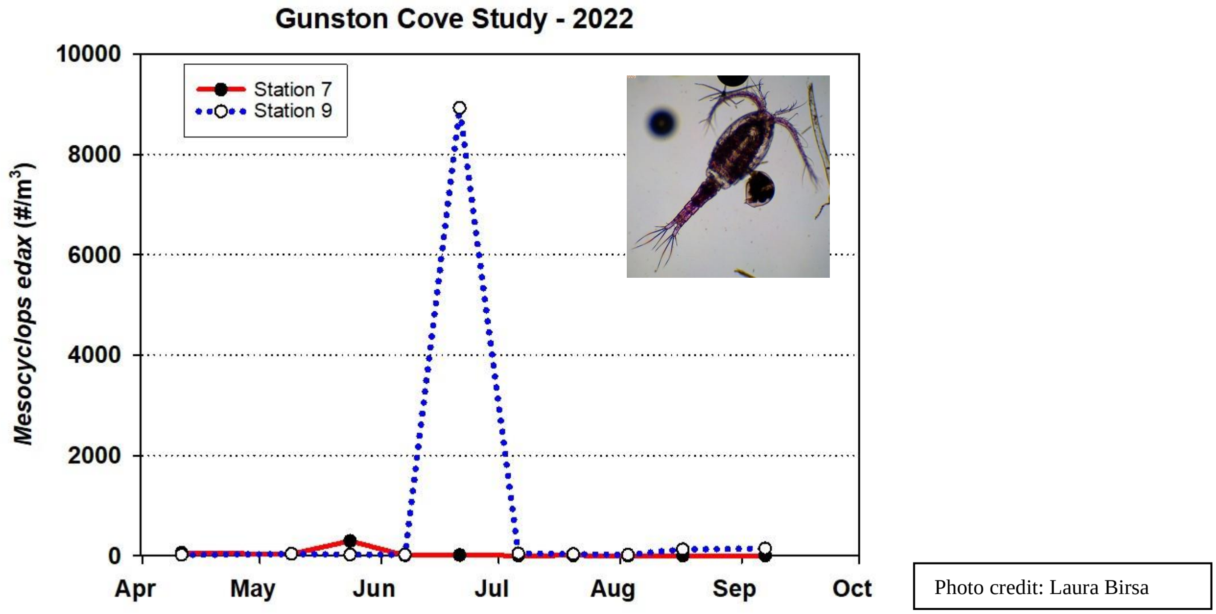


Figure 66. *Mesocyclops edax* by Station (#/m^3).

Mesocyclops edax was very abundant in the cove on one date, reaching a peak of 9,000/m^3 in late June (Figure 66).

E. Ichthyoplankton - 2022

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 2022, we collected 14 samples (7 at Station 7 and 7 at Station 9) during the months April through July and obtained a total of 854 larvae (Table 4), which is on par with previous years (e.g. 1161 in 2021, 1798 in 2020, 1399 in 2019, 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, family level or less (2.69% were unidentified). This year the number of fishes we identified to genus and Family levels were similar to other years. Our identification to family Clupeidae (but not further) was 31.97, which was higher than last year (9.99%), but similar to 2018 (35.4%). Of the Clupeidae we identified to the species level, Gizzard Shad was the dominant species representing 22.13%, with Alewfie and Blueback Herring around 8%. All clupeids together constituted 76.9% of the catch. The dominant non-clupeid species in the catch was White Perch with 13.35% of the catch, similar to previous years and we identified at least 11 species.

The mean density of larvae, which takes the volume of water sampled into account over the time sampled, is shown in Figure 67 and 68. Clupeid larvae in Figure 67 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 peak during mid-May (Figure 67), which is similar to previous years. The abundance of non-clupeid was similar, also peaking in mid-May (Figure 68). Larval density tends to taper off as the summer progresses, as was seen in 2022. The other larvae included all other taxa listed in Table 4.

Table 4. The number of larval fishes collected in Gunston Cove and the Potomac River in 2022.

Scientific Name	Common Name	7	9	Total	% of Total
Alosa aestivalis	Blueback Herring	14	57	71	8.31
Alosa mediocris	Hickory Shad	8	14	22	2.58
Alosa pseudoharengus	Alewife	30	44	74	8.67
Alosa sp.	unk. *Alosa* species	19	9	28	3.28
Carpiodes cyprinus	Quillback	0	1	1	0.12
Clupeidae	unk. clupeid species	169	104	273	31.97
Dorosoma cepedianum	Gizzard Shad	92	97	189	22.13
Eggs	Eggs	1	1	2	0.23
Hybognathus regius	Eastern Silvery Minnow	1	0	1	0.12
Lepomis sp.	unk. Sunfish	11	6	17	1.99
Menidia beryllina	Inland Silverside	17	12	29	3.40
Morone americana	White Perch	15	99	114	13.35
Perca flavescens	Yellow Perch	0	9	9	1.05
Strongylura marina	Atlantic Needlefish	1	0	1	0.12
Unidentified	unidentified	13	10	23	2.69
	Total	**391**	**463**	**854**	

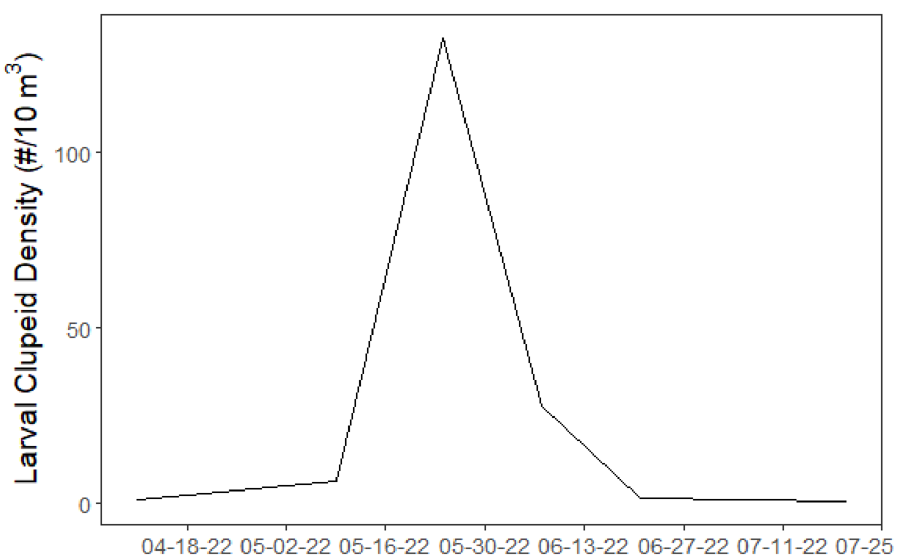


Figure 67. Clupeid larvae, mean density (abundance per 10m^3).

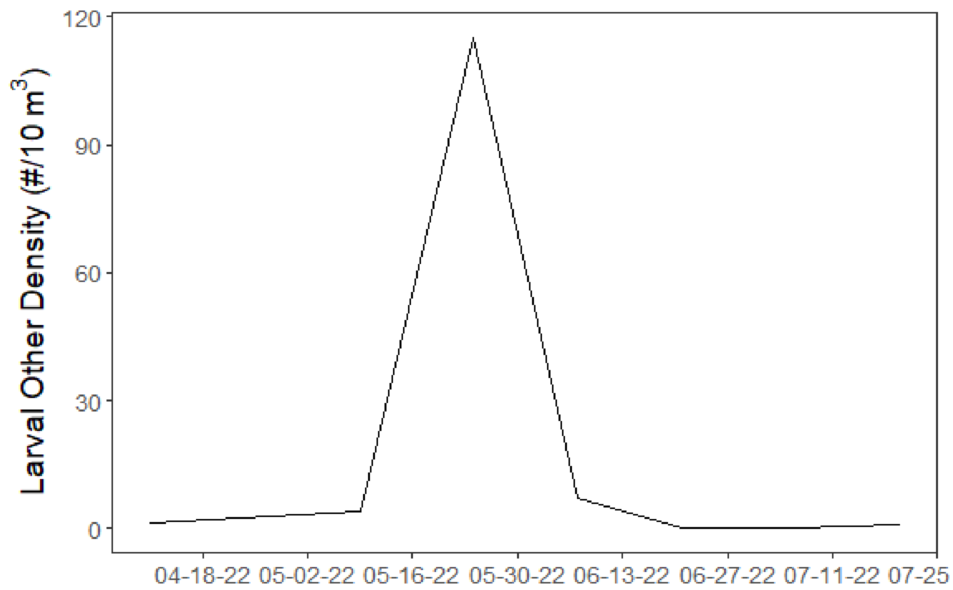


Figure 68. All other larvae, mean density (abundance per 10m^3)

F. Adult and juvenile fishes – 2022

Trawls

We sampled fishes with the trawl from April 29 - September 15 at station 7, 9, and 10. These three fixed stations have been sampled continuously since the inception of the survey. We collected a total of 5272 fishes comprising at least 28 species in all trawl samples combined (Table 5). Like previous years, the dominant species we collected was White Perch (76.02 %), followed by Spottail Shiner (8.00%), and we collected invasive Blue Catfish and Snakehead.

Table 5. Adult and juvenile fish collected by trawling. Total over all dates and stations. 2022.

Scientific Name	Common Name	Abundance	Percent
Morone americana	White Perch	4008	76.02
Notropis hudsonius	Spottail Shiner	422	8.00
Anchoa mitchilli	Bay anchovy	301	5.71
Dorosoma cepedianum	Gizzard Shad	186	3.53
Alosa aestivalis	Blueback Herring	102	1.93
Lepomis gibbosus	Pumpkinseed	53	1.01
Alosa pseudoharengus	Alewife	33	0.63
Etheostoma olmstedi	Tessellated Darter	26	0.49
Alosa sp.	unk. Alosa species	19	0.36
Ictalurus furcatus	Blue Catfish	19	0.36
Lepomis microlophus	Redear Sunfish	17	0.32
Fundulus diaphanus	Banded Killifish	15	0.28
Lepomis macrochirus	Bluegill	14	0.27
Carassius auratus	Goldfish	11	0.21
Morone saxatilis	Striped Bass	7	0.13
Perca flavescens	Yellow Perch	7	0.13
Ameiurus catus	White Bullhead	6	0.11
Hybognathus regius	Eastern Silvery Minnow	6	0.11
Cyprinus carpio	Carp	4	0.08
Lepomis sp.	unk. Sunfish	4	0.08
Micropterus salmoides	Largemouth Bass	3	0.06
Alosa mediocris	Hickory Shad	2	0.04
Ameiurus nebulosus	Brown Bullhead	1	0.02
Carpiodes cyprinus	Quillback	1	0.02
Channa argus	Northern Snakehead	1	0.02
Dorosoma petenense	Threadfin Shad	1	0.02
Enneacanthus gloriosus	Bluespotted Sunfish	1	0.02
Ictalurus punctatus	Channel Catfish	1	0.02
Strongylura marina	Atlantic Needlefish	1	0.02
	Total	**5272**	

The dominant migratory species, White Perch, occurred ubiquitously at all stations on every sampling date, with peak abundance in July (Tables 6 & 7). Spottail Shiner, and Pumpkinseed were also ubiquitous throughout the season occurring on almost all sampling dates (Tables 6 & 7). Although we collected 19 individuals of the Invasive Blue Catfish spread throughout the season, we also collected two of our native Bullhead Catfishes in lower abundances (White = 6, Brown = 1).

In total numbers and species richness of fish, station 10 dominated the other stations by far with 3706 individuals from 22 species (Table 7, Figure 58a). Station 7 had 1487 individuals from 21 species and station 9 had 79 individuals from 10 species (Table 7). White Perch were the dominant species at all stations, dominating shallow deep and mid-water trawls. Similar to last year, Blue Catfish were collected at all trawling stations, with the highest numbers collected at station 9 (n = 9), followed by 7 (n = 6) and 10 (n = 4). This continues our observations of Blue Catfish inside of Gunston Cove, demonstrating that they are not restricted to the mainstem as previously thought and for the second year in a row we have collected them at our interior station 10 trawl. While ubiquitous, we collected most White Perch at our shallow water site (station 10) in July (Table 6, Figure 58a and 59a). Spottail Shiner showed a similar pattern and had highest abundance with 286 individuals at station 10, followed by 7 and 9 (Table 7, Figure 58a). At all stations, White Perch made up the most significant proportion of the total catch at all stations, followed by Spottail Shiners. At site 7, Blueback Herring and Bay Anchovy were also in the top 5 percentage of species collected (Figure 59b).

Similar to their station catch dominance, White Perch also dominated the trawl catch during June and July (Figure 59a and 59b). Spottail shiner and Gizzard Shad were also abundant during these months. Interestingly in September, juvenile Bluebacck Herring constituted 16% of our catch. This indicates that Gunston Cove is valuable juvenile habitat for these imperiled species, and this is the second year in a row September has had substantial *Alosa* catches in Gunston Cove. The most productive month was July, which was due to the large catch of White Perch, followed by Spottail Shiner and Gizzard Shad. April and May catches were low spread between sunfish, Spotail Shiners, and White Perch. However, we did collect the first Snakehead from a trawl sample for the duration of this study during April of this year.

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 6. Adult and Juvenile Fish Collected by Trawling. Gunston Cove Study - 2022.

Scientific Name	Common Name	04-29	05-13	05-26	06-09	06-23	07-14	07-28	08-11	08-25	09-15	Total
Alosa aestivalis	Blueback Herring	0	0	0	0	0	0	1	0	0	101	102
Alosa mediocris	Hickory Shad	0	0	0	0	0	0	1	0	1	0	2
Alosa pseudoharengus	Alewife	0	0	0	1	0	0	0	0	31	1	33
Alosa sp.	unk. Alosa species	0	14	0	4	0	0	0	0	1	0	19
Ameiurus catus	White Bullhead	0	0	1	3	1	0	1	0	0	0	6
Ameiurus nebulosus	Brown Bullhead	0	0	1	0	0	0	0	0	0	0	1
Anchoa mitchilli	Bay anchovy	0	0	0	0	0	0	6	0	10	285	301
Carassius auratus	Goldfish	1	3	3	2	1	1	0	0	0	0	11
Carpiodes cyprinus	Quillback	0	0	0	1	0	0	0	0	0	0	1
Channa argus	Northern Snakehead	1	0	0	0	0	0	0	0	0	0	1
Cyprinus carpio	Carp	1	2	0	0	0	0	0	0	0	1	4
Dorosoma cepedianum	Gizzard Shad	0	0	0	0	16	114	51	0	3	2	186
Dorosoma petenense	Threadfin Shad	0	0	0	0	0	0	0	0	0	1	1
Enneacanthus gloriosus	Bluespotted Sunfish	0	0	1	0	0	0	0	0	0	0	1
Etheostoma olmstedi	Tessellated Darter	0	2	0	7	4	6	1	1	2	3	26
Fundulus diaphanus	Banded Killifish	0	2	0	4	5	1	0	0	0	3	15
Hybognathus regius	Eastern Silvery Minnow	0	0	0	0	0	1	0	0	0	5	6
Ictalurus furcatus	Blue Catfish	1	1	0	5	3	3	2	0	1	3	19
Ictalurus punctatus	Channel Catfish	0	1	0	0	0	0	0	0	0	0	1
Lepomis gibbosus	Pumpkinseed	10	4	4	3	12	10	6	0	2	2	53
Lepomis macrochirus	Bluegill	3	1	7	0	1	0	0	0	0	2	14
Lepomis microlophus	Redear Sunfish	2	2	0	2	1	1	0	0	1	8	17
Lepomis sp.	unk. sunfish	0	0	1	0	0	0	0	0	0	3	4
Micropterus salmoides	Largemouth Bass	0	3	0	0	0	0	0	0	0	0	3
Morone americana	White Perch	25	8	9	71	895	2317	471	1	51	160	4008
Morone saxatilis	Striped Bass	0	0	0	0	1	2	0	0	2	2	7
Notropis hudsonius	Spottail Shiner	17	4	8	39	58	165	81	2	12	36	422
Perca flavescens	Yellow Perch	0	0	0	2	3	1	0	0	1	0	7
Strongylura marina	Atlantic Needlefish	0	0	0	0	0	0	0	0	1	0	1
	Total	61	47	35	144	1001	2622	621	4	119	618	5272

Table 7. Adult and Juvenile Fish Collected by Trawling. Gunston Cove Study – 2022.

Scientific Name	Common Name	7	9	10
Alosa aestivalis	Blueback Herring	102	0	0
Alosa mediocris	Hickory Shad	1	1	0
Alosa pseudoharengus	Alewife	33	0	0
Alosa sp.	unk. Alosa species	2	1	16
Ameiurus catus	White Bullhead	4	0	2
Ameiurus nebulosus	Brown Bullhead	0	0	1
Anchoa mitchilli	Bay anchovy	228	0	73
Carassius auratus	Goldfish	4	0	7
Carpiodes cyprinus	Quillback	0	0	1
Channa argus	Northern Snakehead	0	0	1
Cyprinus carpio	Carp	2	2	0
Dorosoma cepedianum	Gizzard Shad	20	0	166
Dorosoma petenense	Threadfin Shad	1	0	0
Enneacanthus gloriosus	Bluespotted Sunfish	0	0	1
Etheostoma olmstedi	Tessellated Darter	0	1	25
Fundulus diaphanus	Banded Killifish	0	0	15
Hybognathus regius	Eastern Silvery Minnow	0	0	6
Ictalurus furcatus	Blue Catfish	6	9	4
Ictalurus punctatus	Channel Catfish	1	0	0
Lepomis gibbosus	Pumpkinseed	22	0	31
Lepomis macrochirus	Bluegill	6	0	8
Lepomis microlophus	Redear Sunfish	2	0	15
Lepomis sp.	unk. sunfish	1	0	3
Micropterus salmoides	Largemouth Bass	2	0	1
Morone americana	White Perch	920	50	3038
Morone saxatilis	Striped Bass	2	3	2
Notropis hudsonius	Spottail Shiner	126	10	286
Perca flavescens	Yellow Perch	2	1	4
Strongylura marina	Atlantic Needlefish	0	1	0
	Total	1487	79	3706

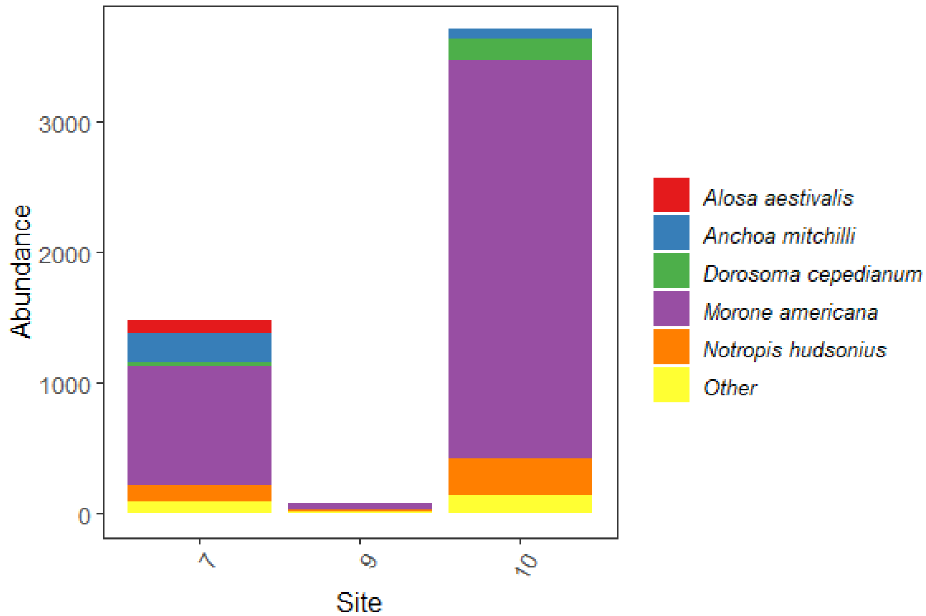


Figure 69a. Adult and Juvenile Fishes Collected by Trawling in 2022. Dominant Species by Site.

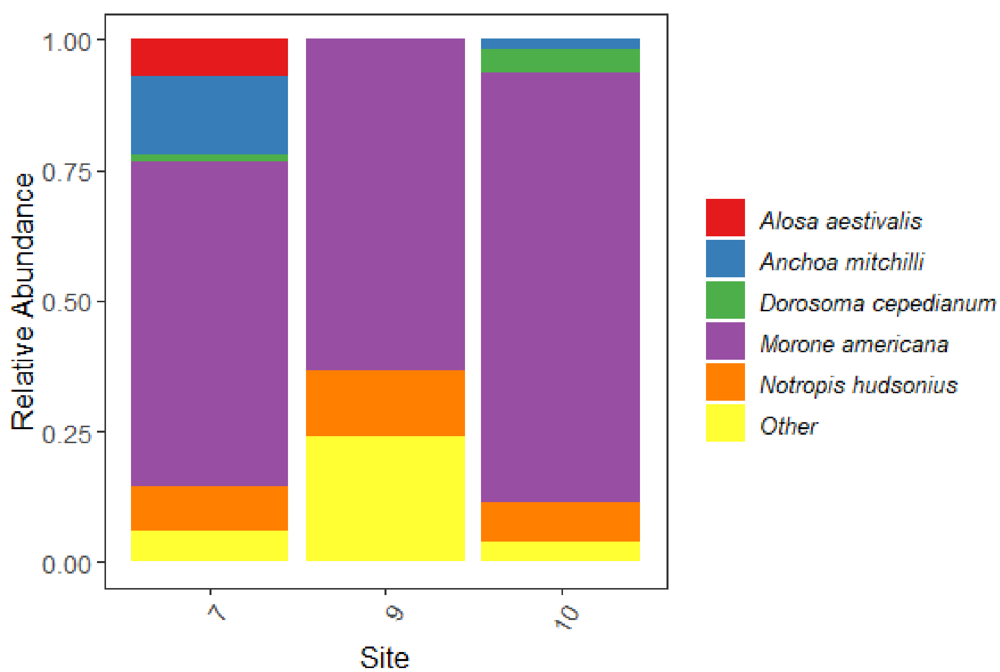


Figure 69b. Relative abundance of Adult and Juvenile Fishes Collected by Trawling in 2022.

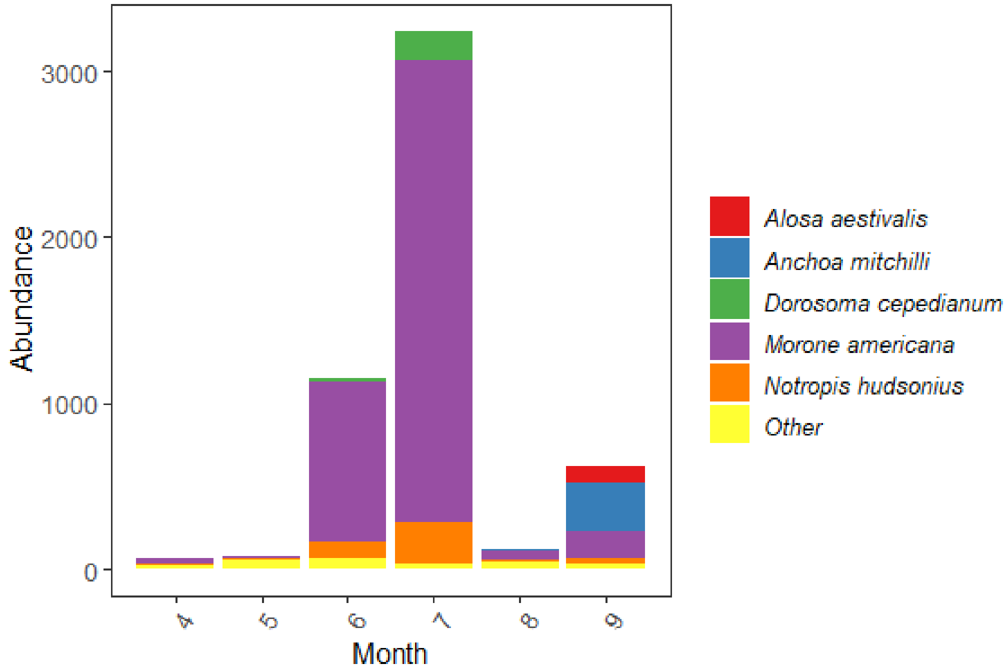


Figure 70a. Adult and Juvenile Fishes Collected by Trawling in 2022. Dominant Species by Month.

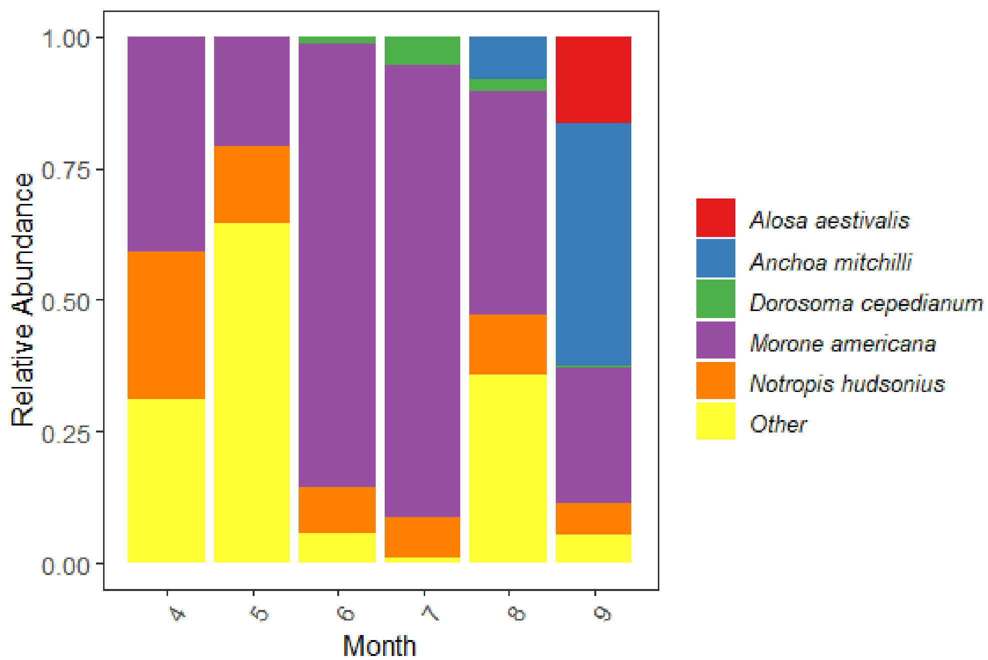


Figure 70b. Relative Abundance for Adult and Juvenile Fishes Collected by Trawling in 2022.

Seines

We conducted seine sampling bimonthly from mid-April to mid-September 2022. 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. In 2022, SAV growth was not as extensive as 2021 at our seine sites, allowing station 4 to be sampled into July.

We completed 36 seine tows, collecting 8,768 fishes of at least 27 species (Table 8). Like previous years, the dominant species in seine catches was Banded Killifish, with a relative contribution to the catch of 53.43 % (n = 4685). Gizzard Shad and Inland Silversides were the next most abundant, comprising 14.95% (n = 1311) and 11.02 % (n = 966) respectively. Other taxa that contributed at least 1% to total abundance included Blueback Herring (4.16%), Tessellated Darter (3.71%), White Perch (3.19%), Mummichog (2.34%), and Mosquitofish (1.60%). All other species contributed to < 1% of the total catch (Table 8).

Banded Killifish was abundant and present at all sampling dates, with highest abundance in June (Table 9, Figure 60). Total catch was dominated by Banded Killifish every sampling date in 2022. The other dominant species by month were Gizzard Shad in June, Inland Silversides in May and August, and Blueback Herring in September (Table 9, Figure 60). This continues the trend of high fall Blueback Herring abundance seen in trawl samples and in 2021.

Banded Killifish was also dominant at all Stations, except for 11 (Table 10, Figure 61). At station 11, Inland Silversides had similar abundances to Banded Killifish and Blueback Herring were the third most abundant at this station. Gizzard Shad was the second most dominant at station 6 and was also present in the top 5 species at station 4B. Station 11 is our most open water site located on a sandy shoreline, so it is not surprising that a pelagic species like Blueback Herring was also abundant at this site.

Table 8. Adult and Juvenile Fish Collected by Seining. Gunston Cove Study - 2022.

Scientific Name	Common Name	Abundance	Percent
Fundulus diaphanus	Banded Killifish	4685	53.43
Dorosoma cepedianum	Gizzard Shad	1311	14.95
Menidia beryllina	Inland Silverside	966	11.02
Alosa aestivalis	Blueback Herring	365	4.16
Etheostoma olmstedi	Tessellated Darter	325	3.71
Morone americana	White Perch	280	3.19
Fundulus heteroclitus	Mummichog	205	2.34
Gambusia holbrooki	Mosquitofish	140	1.60
Dorosoma petenense	Threadfin Shad	82	0.94
Carpiodes Cyprinus	Quillback	71	0.81
Notropis hudsonius	Spottail Shiner	71	0.81
Hybognathus regius	Eastern Silvery Minnow	59	0.67
Morone saxatilis	Striped Bass	52	0.59
Alosa pseudoharengus	Alewife	27	0.31
Alosa sp.	unk. Alosa species	20	0.23
Lepomis auratus	Redbreast Sunfish	20	0.23
Lepomis sp.	unk. sunfish	16	0.18
Lepomis gibbosus	Pumpkinseed	15	0.17
Alosa sapidissima	American Shad	14	0.16
Lepomis macrochirus	Bluegill	13	0.15
Notemigonus crysoleucas	Golden Shiner	12	0.14
Lepomis microlophus	Redear Sunfish	8	0.09
Alosa mediocris	Hickory Shad	4	0.05
Enneacanthus gloriosus	Bluespotted Sunfish	2	0.02
Carassius auratus	Goldfish	1	0.01
Erimyzon oblongus	Creek Chubsucker	1	0.01
Lepisosteus osseus	Longnose Gar	1	0.01
Perca flavescens	Yellow Perch	1	0.01
Strongylura marina	Atlantic Needlefish	1	0.01
	Total	**8768**	

Table 9. Adult and Juvenile Fish Collected by Seining by Date. Gunston Cove Study - 2022.

Scientific Name	Common Name	4-29	5-13	5-26	6-09	6-23	7-14	7-28	8-11	8-25	9-15	Total
Alosa aestivalis	Blueback Herring	0	0	0	0	0	0	0	0	0	365	365
Alosa mediocris	Hickory Shad	0	0	0	2	1	1	0	0	0	0	4
Alosa pseudoharengus	Alewife	0	0	0	0	0	0	0	9	18	0	27
Alosa sapidissima	American Shad	0	0	0	0	1	0	2	3	2	6	14
Alosa sp.	unk. Alosa species	3	2	1	8	6	0	0	0	0	0	20
Carassius auratus	Goldfish	0	0	0	0	0	0	0	0	0	1	1
Carpiodes cyprinus	Quillback	0	0	0	32	30	7	2	0	0	0	71
Dorosoma cepedianum	Gizzard Shad	0	0	0	0	1240	62	2	1	6	0	1311
Dorosoma petenense	Threadfin Shad	0	0	0	0	0	32	11	0	2	37	82
Enneacanthus gloriosus	Bluespotted Sunfish	0	0	0	1	1	0	0	0	0	0	2
Erimyzon oblongus	Creek Chubsucker	0	0	0	0	0	0	0	0	0	1	1
Etheostoma olmstedi	Tessellated Darter	4	20	7	39	19	54	82	30	51	19	325
Fundulus diaphanus	Banded Killifish	345	473	360	1757	307	164	274	316	246	443	4685
Fundulus heteroclitus	Mummichog	14	12	57	3	13	1	29	17	19	40	205
Gambusia holbrooki	Mosquitofish	0	51	3	4	10	14	20	7	22	9	140
Hybognathus regius	Eastern Silvery Minnow	0	0	0	0	3	1	52	2	1	0	59
Lepisosteus osseus	Longnose Gar	0	0	0	0	0	0	0	1	0	0	1
Lepomis auritus	Redbreast Sunfish	0	0	0	1	6	1	0	2	8	2	20
Lepomis gibbosus	Pumpkinseed	0	0	3	3	3	0	4	1	0	1	15
Lepomis macrochirus	Bluegill	7	2	0	1	3	0	0	0	0	0	13
Lepomis microlophus	Redear Sunfish	2	0	2	0	0	1	0	0	0	3	8
Lepomis sp.	unk. sunfish	3	0	1	1	0	0	2	3	6	0	16
Menidia beryllina	Inland Silverside	56	224	259	23	53	10	10	89	229	13	966
Morone americana	White Perch	1	16	0	0	11	6	65	78	63	40	280
Morone saxatilis	Striped Bass	0	0	0	4	8	19	14	3	2	2	52
Notemigonus crysoleucas	Golden Shiner	1	0	1	1	9	0	0	0	0	0	12
Notropis hudsonius	Spottail Shiner	3	8	0	1	1	0	17	17	7	17	71
Perca flavescens	Yellow Perch	0	0	0	0	1	0	0	0	0	0	1
Strongylura marina	Atlantic Needlefish	0	0	0	0	0	0	1	0	0	0	1
	Total	439	808	694	1881	1726	373	587	579	682	999	8768

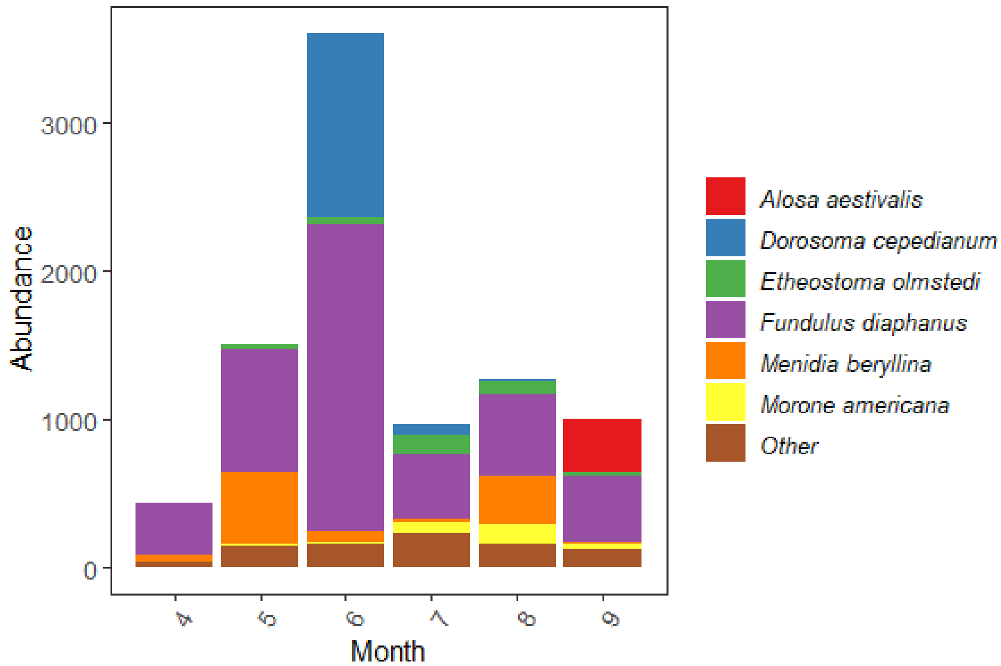


Figure 71. Adult and Juvenile Fish Collected by Seining in 2022. Dominant Species by Month.

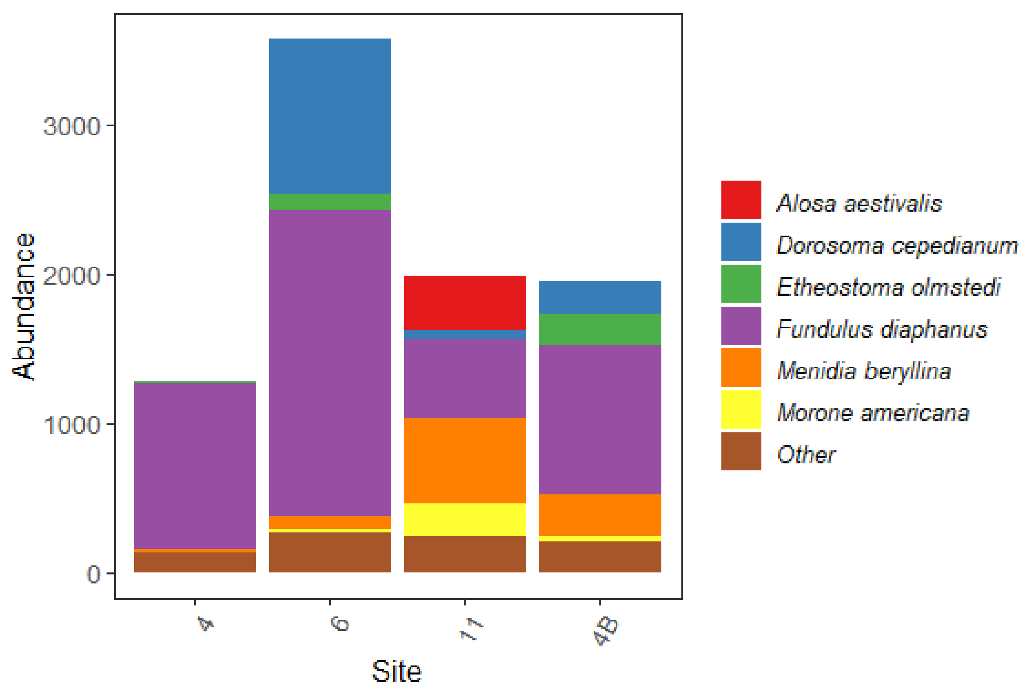


Figure 72. Adult and Juvenile Fishes Collected by Seining in 2022. Dominant Species by Station.

Table 10. Adult and Juvenile Fish Collected by Seining in 2022 by station in Gunston Cove.

Scientific Name	**Common Name**	**4**	**6**	**11**	**4B**
Alosa aestivalis	Blueback Herring	0	0	365	0
Alosa mediocris	Hickory Shad	0	1	3	0
Alosa pseudoharengus	Alewife	0	0	27	0
Alosa sapidissima	American Shad	0	1	7	6
Alosa sp.	unk. Alosa species	6	8	3	3
Carassius auratus	Goldfish	0	1	0	0
Carpiodes cyprinus	Quillback	1	1	26	43
Dorosoma cepedianum	Gizzard Shad	0	1037	62	211
Dorosoma petenense	Threadfin Shad	0	0	82	0
Enneacanthus gloriosus	Bluespotted Sunfish	0	1	0	1
Erimyzon oblongus	Creek Chubsucker	0	0	0	1
Etheostoma olmstedi	Tessellated Darter	12	101	2	210
Fundulus diaphanus	Banded Killifish	1115	2048	523	999
Fundulus heteroclitus	Mummichog	53	76	3	73
Gambusia holbrooki	Mosquitofish	51	58	0	31
Hybognathus regius	Eastern Silvery Minnow	0	50	9	0
Lepisosteus osseus	Longnose Gar	0	1	0	0
Lepomis auritus	Redbreast Sunfish	1	13	0	6
Lepomis gibbosus	Pumpkinseed	1	7	1	6
Lepomis macrochirus	Bluegill	3	8	0	2
Lepomis microlophus	Redear Sunfish	1	2	0	5
Lepomis sp.	unk. sunfish	1	5	8	2
Menidia beryllina	Inland Silverside	22	87	572	285
Morone americana	White Perch	1	28	215	36
Morone saxatilis	Striped Bass	0	2	45	5
Notemigonus crysoleucas	Golden Shiner	6	5	0	1
Notropis hudsonius	Spottail Shiner	4	20	31	16
Perca flavescens	Yellow Perch	1	0	0	0
Strongylura marina	Atlantic Needlefish	0	1	0	0
	Total	**1279**	**3562**	**1984**	**1942**

Fyke Nets

We added fyke nets to the sampling regime in 2012 to better represent the fish community present within SAV beds. In 2022 we collected a total number of 523 specimens of at least 15 species in the two fyke nets (Station Fyke 1 and Station Fyke 2; Figure 62; Table 11), like our 2021 catches. The dominant species in Fyke net collections were all Sunfish species (all *Lepomis* sp.) combined (28.64%), followed by Inland Silversides (26.00 %) and Banded Killifish (18.86 %). Other taxa contributing more than 1% of the catch include White Perch, *Alosa* sp., Tessellated Darter, and Spottail Shiner (Table 11).

Highest abundances were collected from June - August, with June dominated by Alosas and Inland Silversides, July dominated by White Perch and Banded Killifish, and August dominated by *Lepomis* sp. and Banded Killifish (Table 12, Figure 62). Interestingly, Inland Silversides were dominant in earlier samples, but absent in later samples. The SAV cover is highest in August, which could preclude inland silversides, given that they are an upper water column pelagic fish. Furthermore, SAV abundance is highest in August, which likely led to greater catches of the SAV associated species (*Lepomis* sp. and Banded Killifish) during these months.

Table 11. Adult and Juvenile Fish Collected by Fyke Nets. Gunston Cove Study - 2022.

Scientific Name	**Common Name**	**Abundance**	**Percent**
Menidia beryllina	Inland Silverside	136	26.00
Fundulus diaphanus	Banded Killifish	99	18.86
Lepomis macrochirus	Bluegill	80	15.25
Morone americana	White Perch	66	12.67
Lepomis gibbosus	Pumpkinseed	45	8.58
Alosa sp.	unk. Alosa species	28	5.44
Etheostoma olmstedi	Tessellated Darter	22	4.27
Lepomis microlophus	Redear Sunfish	16	2.98
Notropis hudsonius	Spottail Shiner	11	2.05
Lepomis sp.	unk. Sunfish	10	1.83
Morone saxatilis	Striped Bass	2	0.39
Dorosoma cepedianum	Gizzard Shad	2	0.38
Pomoxis nigromaculatus	Black Crappie	2	0.38
Alosa pseudoharengus	Alewife	2	0.37
Alosa mediocris	Hickory Shad	1	0.20
Ameiurus nebulosus	Brown Bullhead	1	0.19
Lepomis auritus	Redbreast Sunfish	1	0.17
	Total	**523**	

Table 12. Adult and Juvenile Fish Collected by Fyke Nets by Date. Gunston Cove Study - 2022.

Scientific Name	Common Name	4-29	5-13	05-26	6-09	6-23	7-14	7-28	8-11	8-25	9-15	Total
Alosa mediocris	Hickory Shad	0	0	0	0	0	1	0	0	0	0	1
Alosa pseudoharengus	Alewife	0	0	0	2	0	0	0	0	0	0	2
Alosa sp.	unk. Alosa species	0	0	0	28	0	0	0	0	0	0	28
Ameiurus nebulosus	Brown Bullhead	0	0	0	0	1	0	0	0	0	0	1
Dorosoma cepedianum	Gizzard Shad	0	0	0	0	1	1	0	0	0	0	2
Etheostoma olmstedi	Tessellated Darter	0	0	0	2	1	5	0	4	5	5	22
Fundulus diaphanus	Banded Killifish	1	0	0	1	0	5	17	25	30	20	99
Lepomis auritus	Redbreast Sunfish	0	0	0	0	0	0	0	1	0	0	1
Lepomis gibbosus	Pumpkinseed	0	0	1	1	0	6	10	14	12	0	45
Lepomis macrochirus	Bluegill	0	0	0	0	0	0	2	42	34	2	80
Lepomis microlophus	Redear Sunfish	0	0	0	0	0	0	1	3	4	8	16
Lepomis sp.	unk. sunfish	0	0	0	0	0	1	2	4	3	0	10
Menidia beryllina	Inland Silverside	52	23	5	49	3	4	0	0	0	0	136
Morone americana	White Perch	0	1	0	0	3	24	15	22	1	1	66
Morone saxatilis	Striped Bass	0	0	0	0	0	1	1	0	0	0	2
Notropis hudsonius	Spottail Shiner	0	0	1	0	2	1	1	1	4	1	11
Pomoxis nigromaculatus	Black Crappie	0	1	0	0	1	0	0	0	0	0	2
	Total	**53**	**25**	**6**	**83**	**12**	**49**	**49**	**116**	**93**	**37**	**523**

Fyke 1 catches were greater than Fyke 2 for all fishes (410 vs. 113 specimens; Table 13, Figure 63). Fyke 1 was dominated by Lepomis and Banded Killifish, but Alosa sp., Inland Silversides and White Perch were also present in the top 5 species. Fyke 2 was dominated by Inland Silversides, with relatively few catches of other species (Figure 63). This trend was likely driven by the fact that Fyke 2 was in an area of less dense SAV for much of the sampling season. Overall, the community structure collected with the two fyke nets was similar; however, Black Crappie and Alewife were collected in Fyke 2, but not in Fyke 1 (Figure 63).

Table 13. Adult and Juvenile Fish Collected by Fyke Nets. Gunston Cove Study - 2022.

Scientific Name	**Common Name**	**Fyke 1**	**Fyke 2**
Alosa mediocris	Hickory Shad	1	0
Alosa pseudoharengus	Alewife	0	2
Alosa sp.	unk. Alosa species	28	0
Ameiurus nebulosus	Brown Bullhead	1	0
Dorosoma cepedianum	Gizzard Shad	2	0
Etheostoma olmstedi	Tessellated Darter	13	10
Fundulus diaphanus	Banded Killifish	97	2
Lepomis auritus	Redbreast Sunfish	1	0
Lepomis gibbosus	Pumpkinseed	35	10
Lepomis macrochirus	Bluegill	72	7
Lepomis microlophus	Redear Sunfish	15	1
Lepomis sp.	unk. sunfish	7	3
Menidia beryllina	Inland Silverside	70	66
Morone americana	White Perch	57	9
Morone saxatilis	Striped Bass	2	0
Notropis hudsonius	Spottail Shiner	9	2
Pomoxis nigromaculatus	Black Crappie	0	2
	Total	**410**	**113**

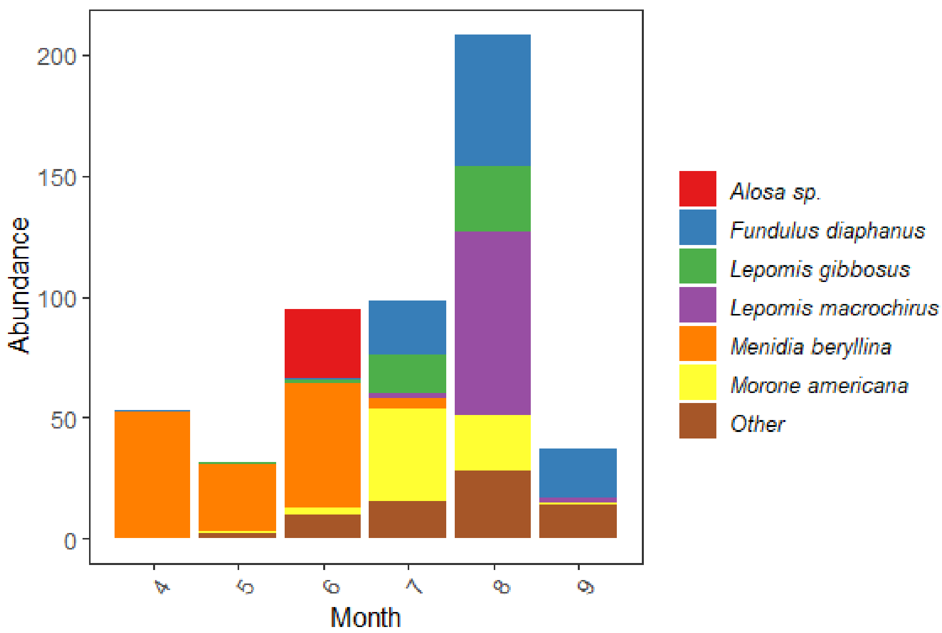


Figure 73. Adult and Juvenile Fish Collected by Fyke Nets. Dominant Species by Month. 2022.

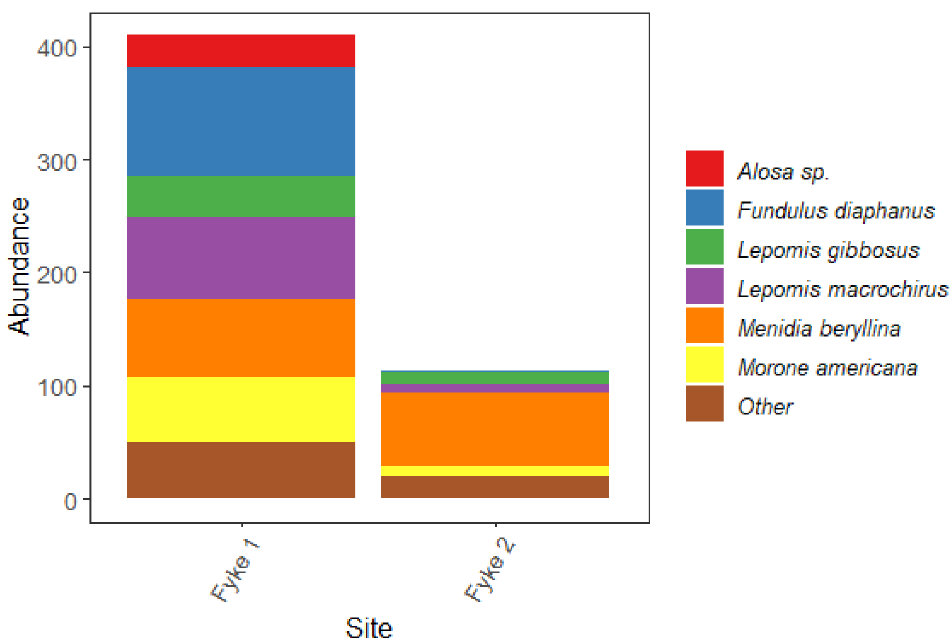


Figure 74. Adult and Juvenile Fishes Collected by Fyke Nets. Dominant Species by Station. 2022.

G. Benthic Macroinvertebrates - 2022

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

Taxonomic Groups: A total of 10 taxa of benthic macroinvertebrates, belonging to 5 orders and 10 families, were recorded during the survey. Two species were non-native (i.e., the Asian clam, *Corbicula fluminea* and the Japanese mystery snail, *Heterogen japonica*). Annelid worms, specifically Oligochaetes, were found in high numbers at both sites over all dates (Figure 75). Overall, they accounted for 68% of all benthic organisms found. Insects were the second highest group in abundance across sites and dates, accounting for 26% of all individuals accounted for. Chironomids were by far the most numerous and omnipresent insect taxon. The other insect taxa was the family Philpotamidae, which was only found at GC9 in June. Crustaceans (including amphipods and isopods) were the third highest group in abundance across sites and dates, accounting for 5% of all individuals. Gammarid amphipods (scuds) dominated this group with the isopod *Cyathura polita* being the second most common crustacean, and isopods from the family Chiridota only found at GC9 in June and August (Figure 75). The remainder of the taxonomic groups accounted for minor components of the overall abundance. These included Bivalvia (0.2% of total abundance), Gastropoda (snails) (0.05%), and Platyhelminthes (flatworms) (0.05%). The bivalve group was composed only of the invasive Asian clam, *Corbicula fluminea*, and the gastropods only had a single member, the invasive Japanese mystery snail *Heterogen japonica* (both found only at GC9).

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

		Average # / ponar	
Taxon	Common Name	GC7	GC9
Platyhelminthes	Flatworms	0	2
Annelida-Oligochaeta*	Oligochaete worms	82.3	91.2
Annelida-Hirundea	Leeches	1	0
Gastropoda-Viviparidae	Mystery snails	0	2
Bivalva-Corbicula*	Asiatic clams	0	2.5
Crustacea-Isopoda-Cyathura*	Isopods	0	2.3
Crustacea-Isopoda-Chiridota	Isopods	0	1.8
Crustacea-Amphipoda-Gammarus*	Amphipods	1.3	18
Insecta-Diptera-Chironomidae*	Midges	62.8	3.9
Insecta-Trichoptera-Philpotamidae	Caddisflies	0	5
	TOTAL	147.4	128.7

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

Spatial trends: Chironomidae insect larvae and Oligochaeta worms were found at both sites and in every replicate every month. The average abundance of organisms per ponar sample was higher at GC7 within Gunston Cove as compared to the site in the Potomac mainstem (GC9), but this was entirely attributable to the large number of Chironomidae insect larvae at GC7 (Figure 75A). Throughout the summer months, the number of Chironomidae insect larvae in the replicate samples contained between 20 and 58 larvae. GC9 had a higher diversity of taxa (N=9) than GC7 (N=4), 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. Platyhelminthes flatworms, the invasive Japanese mystery snail *Heterogen japonica*, the Asian clam *Corbicula fluminea*, the isopoda *Cyathura polita* and Chiridota, and the Philpotamidae insect family were present only at GC9. However, Hirundea (leeches) were only found at GC7. Oligochaeta were present in about the same abundances at both sites. When examining all non-Annelida taxa, Insects were the dominant group in percent contribution at GC7 (98%) and Crustaceans were the most dominant group at GC9 (59%) (Figure 75). Other taxa varied in their percent contribution by site.

Temporal trends: Annelida, composed of only oligochaetes, were the dominant taxa recorded during all months (Figure 75). Crustaceans, driven by Gammarid amphipods, and Insecta, driven by the Chironomidae family, both peaked during June. Average Bivalvia abundances differed monthly across the sampling period (average of 1-5 individuals/ponar) but these trends were driven by GC9 as there was no clams collected at GC7. Comparing percent contributions of all non-Annelida taxa across all of the sites, months were dominated by Insecta, which accounted for 79-91% (Figure 75). 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.

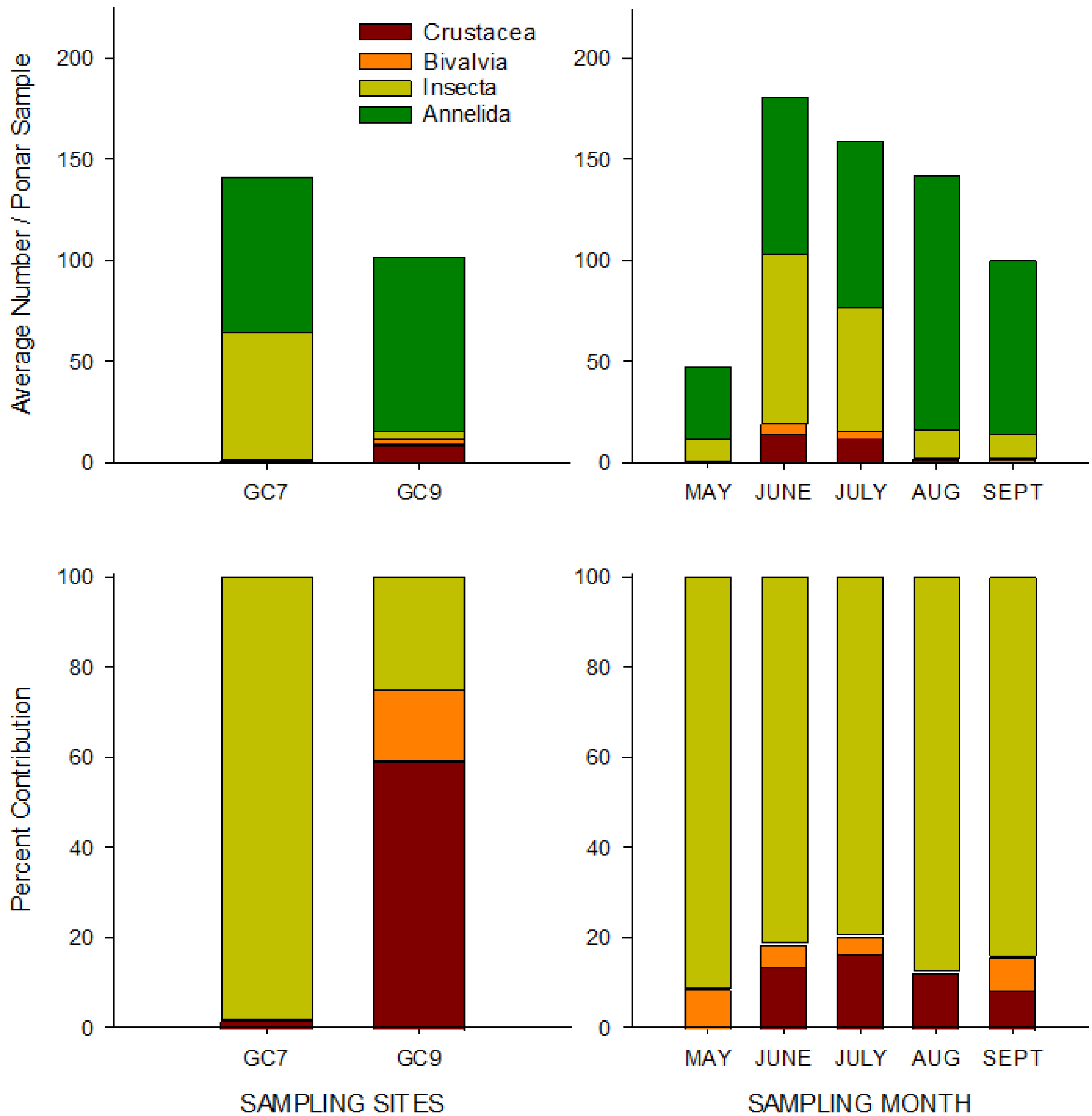


Figure 75. Average number per ponar sample of all benthic macroinvertebrate taxa (A, B) and percent contribution of all non-Annelida benthic macroinvertebrate (C, D) in petite ponar samples collected in 2022 separated by site and month.

Multivariate analyses: **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 14) 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 (10 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 fourth-root transformed data is shown in Figure 76. All of the GC7 samples separate from the GC9 samples, as noted by the two circles of data points. The May and August GC7 samples (blue and red icon in the left, middle) were different from the other months because these were the only months in which Gammarid crustaceans were not found in GC7 samples. May and August also only contained two taxa – Oligochaeta and Chironomidae – while all other samples had at least three taxa. The GC7 samples had either 2 or 3 taxa as compared to between 2 and 5 taxa in GC9 samples. The higher richness at GC9 is probably due to better habitat conditions especially large and more heterogeneous sediment particle size. The spread of the GC9 samples represent the numbers of taxa present in the samples; July and September (green and purple icons) both had 5 taxa present. May and June GC9 were different from all other samples in that there were only three taxa present. August was separated out because it was the only month in which *Corbicula* clams were not present.

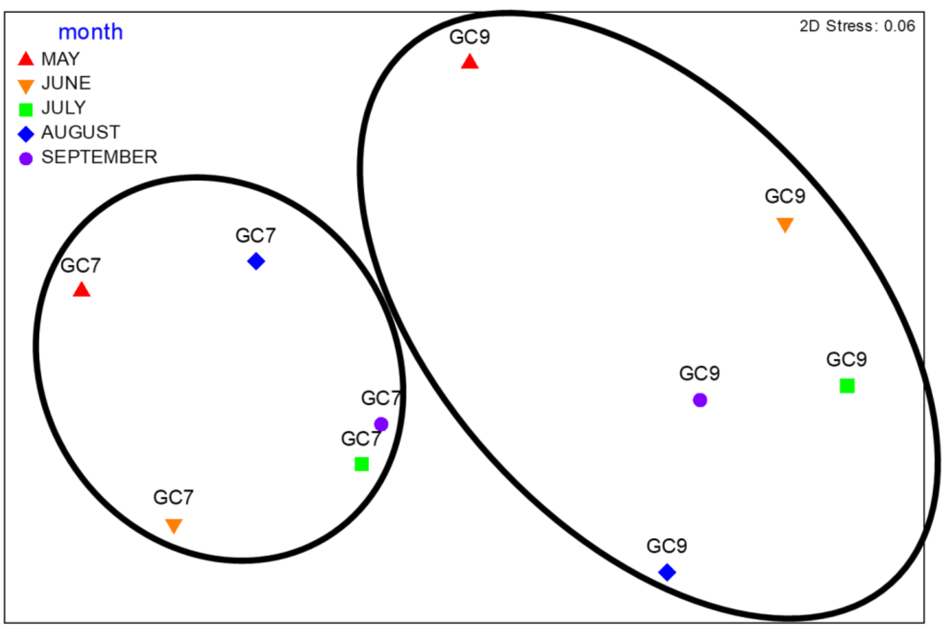


Figure 76. nMDS ordination of benthic samples from tidal stations. The station names are placed above each symbol. Colors represent month. Triplicates were averaged to get a single value for each month-station combination. Data was fourth root transformed, and the distance measure was S17 Bray Curtis similarity.

Influence of Habitat on Community Composition: For this analysis, we assigned all materials greater than 5 mm in the petite ponar sample to one of three categories: leaves/woody debris, mollusc shells, or rocks/sand and calculated the percent contribution of each category to the overall habitat (Table 15). Submerged aquatic vegetation (SAV) was recovered at GC7 in only one replicate in August. In comparison, SAV was documented from GC9 in one replicate in June and two replicates in July. Both GC7 and GC9 are shelly sites (average 56.6% and 63.5%, respectively), with the shell matrix composed of mostly dead Asian clam shells. At GC7, macroinvertebrate richness and abundance was correlated with the type of large particles available; as the percent organic matter decreased and the percent shell increased, taxa richness and abundance increased (r = 0.47 and r = 0.31, respectively) (Table 15). At GC9, the trend was similar, but the relationship was not as strong. As the percent shell increased, taxa richness and abundance increased (r = 0.12 and r = 0.27, respectively).

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

Site	Replicate	Month	% Leaves/Wood	% Shell	% SAV	Total Abundance	Total Richness
GC7	A	May	60.0	40.0	0.0	73	2
	B		4.9	95.1	0.0	66	2
	C		54.2	45.8	0.0	44	2
	A	June	83.6	15.5	0.0	128	2
	B		10.3	89.7	0.0	239	2
	C		23.9	76.0	0.0	248	3
	A	July	69.0	30.6	0.0	236	2
	B		4.4	95.6	0.0	297	3
	C		1.3	98.7	0.0	255	3
	A	August	83.8	14.7	0.0	161	2
	B		67.9	21.4	0.0	120	2
	C		26.3	70.2	0.6	73	2
	A	September	5.9	94.1	0.0	62	3
	B		77.4	22.6	0.0	88	3
	C		61.5	38.5	0.0	92	2
GC9	A	May	43.6	56.4	0.0	49	2
	B		100.0	0.0	0.0	23	3
	C		81.0	19.0	0.0	22	2
	A	June	89.8	7.8	0.1	205	6
	B		61.9	37.5	0.0	50	3
	C		41.8	58.2	0.0	121	3
	A	July	3.5	96.5	0.0	67	4
	B		4.1	95.6	0.1	71	5
	C		3.0	96.9	0.1	191	5
	A	August	18.1	81.7	0.0	138	4
	B		9.8	88.4	0.0	183	4
	C		53.4	44.6	0.0	177	5
	A	September	6.7	93.3	0.0	126	4
	B		18.4	81.6	0.0	92	4
	C		5.3	94.7	0.0	132	2

Summary: Similar to previous years, the macroinvertebrate community was dominated by Oligochaetes (Annelids) across sites. Outside of the Annelids, Crustaceans (dominated by gammarid amphipods) were the most abundant group in the Potomac River mainstem (Station GC9), while Gunston Cove proper (Station GC7) was dominated by Insect larvae from the Chironomidae family (midges). GC9 had a higher number of unique taxa (N=6; Platyhelminthes flatworms, the invasive Japanese mystery snail *Heterogen japonica*, the Asian clam *Corbicula fluminea*, the isopoda *Cyathura polita* and Chiridota, and the Philpotamidae insect family). Comparing percent contributions of all non-Annelida taxa across both sites, months were dominated by Insecta (Chironomidae midges) in all months (Figure 75). Ordination analyses of the community indicated a clear separation between communities sampled at the two sites for all months. Both sites are shell dominated, and there was a positive relationship between large particle type and total macroinvertebrate abundance or richness at both sites. There was also a change of the community composition throughout the months, as common for aquatic communities experiencing changes in abiotic conditions and recruitment during the summer months.

H. Submersed Aquatic Vegetation – 2022

The Virginia Institute of Marine Science annual aerial SAV survey from 2022 indicated a continued slow decline over most of the inner Cove area that began in 2020 after 15 years of coverage values between 150 and 200 ha (Figure 77). For 2022, the total SAV coverage in the cove was approximately 120 hectares, lower than in 2021, but still substantial.

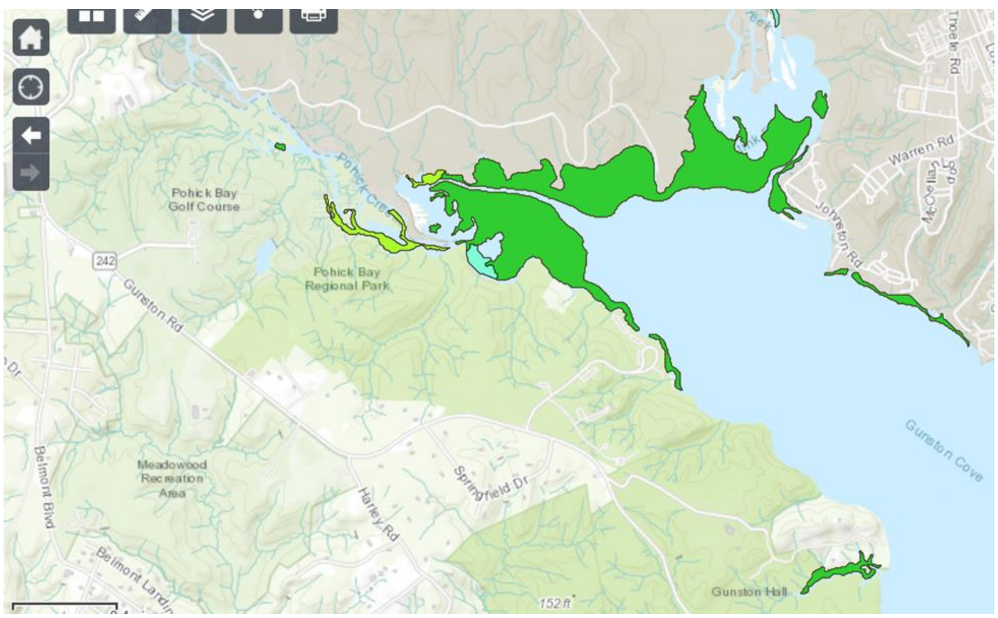


Figure 77. Coverage of Submersed Aquatic Vegetation in Gunston Cove. 2022. VIMS SAV program. Interactive SAV map for 2022. https://mobjack.vims.edu/sav/savwabmap/
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During the data mapping cruise, the distribution of dominant SAV taxa was determined at 31 points in the inner portion of Gunston Cove with depth 1.7 m or less during the data mapping cruise on August 3, 2022 by inserting a garden rake to the bottom, twisting it to collect plants and pulling it on board. The results are summarized in Table 16. *Hydrilla verticillata* was found at about 2/3 of the shallow water sites and its coverage at those sites was fairly high. *Certatophyllum demersum* was also found at about a quarter of the shallow water sites with somewhat less average coverage. *Najas minor* was found at about 1/3 of these sites at moderate coverage. *Zosterella dubia* was present at about half of the sampled points at low to moderate density. Note that some of the data mapping cruise occurred outside of the area of SAV coverage and that some of the heaviest areas of SAV could not be sampled on the data mapping cruise because the boat could not navigate heavy SAV (Figure 6).

Table 16. Relative abundance of dominant SAV species determined during data mapping cruise. August 3, 2022.

Scientific Name	**Common Name**	**Freq (#)**	**Freq (%)**	**Avg. Density**
Hydrilla verticillate	hydrilla	21	67.7	1.74
Ceratophyllum demersum	coontail	7	22.5	1.21
Najas minor	minor/spiny naiad	11	35.5	1.05
Vallisneria americana	water celery	0	0	0
Zosterella dubia	water stargrass	0	0	0

A total of 31 points were sampled for SAV with a water depth of 1.7 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. 2022 Data

In 2022 temperature was above normal in all months (Table 3). There were 34 days with maximum temperature above 32.2ºC (90ºF) as compared to 38 in 2021, both of which are well above the median number over the past decade. Precipitation was closer to normal in 2022 than in the extremely wet year 2018. However, it was again well above normal in 2022, especially in May and July. Rainfall and runoff patterns relative to sampling dates are shown in Figure 78. Sample dates in April, May, and early June could have been impacted by rainfall producing tributary flows. River flows which could impact the study area occurred in early May.

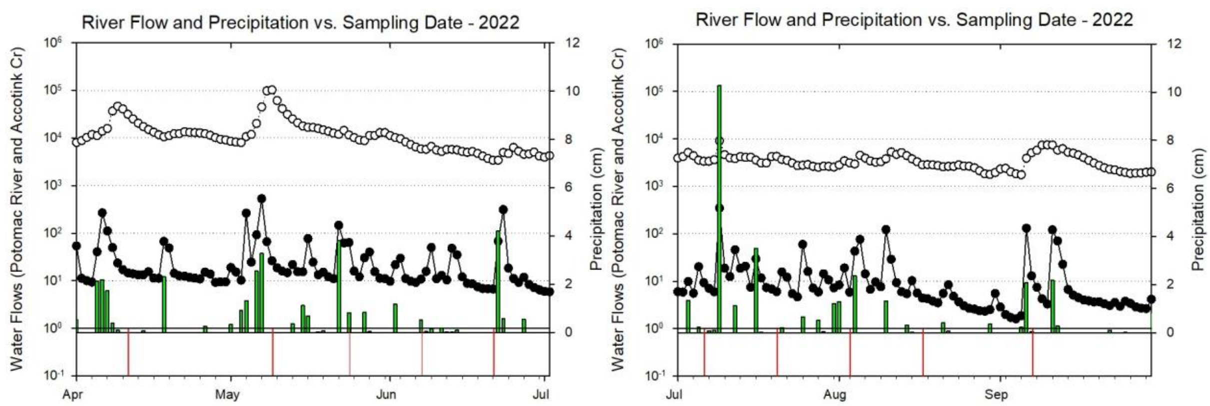


Figure 78. Precipitation (green bars), Accotink Creek flows (solid circles), Potomac River flows (open circles) and water quality/plankton sampling events (red lines at bottom).

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 was mostly in the 250-400 range and increased through the year at both stations with little difference between the two on most dates. Dissolved oxygen saturation and concentration (DO) were consistently higher in the river in the spring and in the cove in the summer. Field pH patterns mirrored those in DO. Total alkalinity was generally higher in the river than in the cove with a general upward trend through the year. Water clarity as measured by Secchi disk transparency and light attenuation coefficient was generally better in the river than in the cove. Values indicated only moderately good water clarity.

Ammonia nitrogen rarely exceeded the rather high detection limit of 0.1 mg/L making analysis of any temporal or spatial trends impossible. Nitrate values declined steadily through August at both stations with river values consistently about 0.5 mg/L than those in the cove. Nitrite was much lower overall. Organic nitrogen was generally fairly consistent through the year and about 0.1 mg/L higher in the cove than in the river. Total phosphorus was generally higher in the cove showed a little seasonal pattern. Soluble reactive phosphorus was consistently higher in the river, but showed little consistent seasonal trend. N to P ratio was about 20 in the river and 10 in the cove, a range which is still indicative of P limitation of phytoplankton and SAV. BOD was generally higher in the cove than in the river. TSS was consistently between 10 and 30 in the river and 20 to 50 in the cove and varied a lot from week to week. VSS showed similar spatial and temporal patterns.

In the cove algal populations as measured by chlorophyll *a* increased steadily through May and June reaching a peak of about 40 µg/L in late June and remaining above 30 µg/L through August. In the river there was a steady increase through spring and early summer reaching about 25 ug/L in late July. In 2022 phytoplankton density in the cove was dominated by cyanobacteria on all dates. *Oscillatoria* was the dominant cyanobacterial taxon early in the year, but was displaced by *Gomphosphaeria* from late June on. In terms of biovolume the dominant group were the diatoms with the most abundant species being the filamentous diatom *Melosira* on most dates. The dominant group in terms of cell density in the river was again the cyanobacteria and the dominant taxon on many dates was either *Oscillatoria* or *Gomphosphaeria.* In terms of biovolume diatoms were again were the dominant group on most dates as in the cove. In the spring and early summer *Melosira* shared dominance with *Cocconeis* and *Surrirella*. In both the cove and the river, the peak in cell density occurred in late June.

Rotifers continued to be the most numerous microzooplankton in 2022. Rotifer densities in the cove exhibited two distinct peaks each dominated by a different genus, *Filinia* in late May and *Brachionus* in late June. Rotifer densities were consistently lower in the river than in the cove with *Brachionus a*s the dominant. *Bosmina*, a small cladoceran exhibited a very distinct peak in the cove in mid-May, but otherwise values were very low. *Diaphanosoma*, a larger cladoceran, was moderately abundant in both areas with maxima in both cove and river in early June and a second similar maximum near $1000/m^3$ in the river in mid July. *Daphnia* displayed much higher than normal peaks in 2022. Cove levels were over $3000/m^3$ in late May and the river reached $1500/m^3$ in mid June.. *Leptodora* exhibited a very strong peak in the cove in late May at over $2500/m^3$. Copepod nauplii followed a clean unimodal pattern in the river exceeding 200/L in late June. Values were somewhat lower and more variable in the river. The calanoid copepod *Eurytemora* was quite abundant in the cove in mid-May attaining $6000/m^3$, but was much lower for the rest of the year. *Eurytemora* attained a value of about $3000/m^3$ in the river in mid-June. A second calanoid *Diaptomus* was found at much lower levels. *Mesocyclops edax* had a strong maximum in the river in mid-July of about $9000/m^3$, but otherwise was quite rare.

In 2022 ichthyoplankton was dominated by clupeids, most of which were Gizzard Shad (22%), Alewife (8.7%), and Blueback Herring (8.3). White Perch was found in relatively high densities (13.4%), mostly found in the Potomac mainstem, confirming its affinity for open water. Inland Silverside was also relatively abundant (3.4%). The highest density of fish larvae occurred mid May, which was driven by a high density of Clupeid larvae. White perch larvae also reached a maximum in May.

Submerged aquatic vegetation continued to be abundant in 2022, which resulted in fish abundances and gear efficiency that was similar to the years before 2018. In trawls White Perch dominated at 76%, followed by Spottail Shiner at 8%, and then Bay Anchovy at 5.7%. No other species exceeded 5%. White Perch was by far the most abundant species and was found in all months at all stations. We collected a lot less Blue Catfish than in 2018, but still found 9 in the mainstem and 10 in the cove. In previous years we found more Blue Catfish in the mainstem versus the cove, which if true would suggest that the coves could serve as refuges for native catfishes. We collected 1 native bullhead catfish and 6 white bullheads in the cove and none in the mainstem.

In seines, the most abundant species in 2022 was Banded Killifish comprising 53% of the catch. 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). Other taxa with high abundances were Gizzard Shad (15%), and Inland Silverside (11%). Abundances remained substantial throughout the sampling season.

In fyke nets Inland Silverside was the dominant species in 2022 with 26% of the total catch. Sunfish (*Lepomis* species lumped together) were also abundant at 24% and Banded Killifish at 19%. White perch were rare in the fyke nets.

As in most previous years, oligochaetes were the most common invertebrates collected in ponar samples in 2022. Chironomids (midge larvae) were second most dominant in the cove and third most dominant in the river. The second most numerous taxon in the river was Amphipoda. Multivariate analysis showed a clear and consistent difference between cove benthic communities and those in the river. Shells were consistently the most abundant large substrate in river benthic samples. In the cove both shells and plant debris were abundant.

Hydrilla verticillata was found at about 2/3 of the shallow water sites and its coverage at those sites was fairly high. *Certatophyllum demersum* was also found at about a quarter of the shallow water sites with somewhat less average coverage. *Najas minor* was found at about 1/3 of these sites at moderate coverage. Areal coverage maps from VIMS were not available for 2022 at the time of this report.

B. Water Quality Trends: 1983-2022

To assess long-term trends in water quality, data from 1983 to 2022 were pooled into two data files: one for Mason data and one for Noman Cole laboratory data. Then, subgroups were selected based on season and station. For water quality parameters, we focused on summer (June-September) data as this period is the most stable and often presents the greatest water quality challenges and the highest biological activity and abundances. We examined the cove and river separately with the cove represented by Station 7 and the river by Station 9. We tried several methods for tracking long-term trends, settling on a scatterplot with LOWESS trend line. Each observation in a particular year is plotted as an open circle on the scatterplot. The LOWESS (locally weighted sum of squares) line is drawn by a series of linear regressions moving through the years. We also calculated the Pearson correlation coefficient and performed linear regressions to test for statistical significance of a linear relationship over the entire period of record (Tables 17 and 18). This was similar to the analysis performed in previous reports.

Table 17
Correlation and Linear Regression Coefficients
Water Quality Parameter vs. Year for 1984-2022
GMU Water Quality Data
June-September

	Station 7			Station 9		
Parameter	Corr. Coeff.	Reg. Coeff.	Signif.	Corr. Coeff.	Reg. Coeff.	Signif.
Temperature	0.181	0.046	0.001 (349)	0.118	0.027	0.041 (303)
Conductivity, standardized to 25°C	0.124	1.286	0.022 (338)	0.013	-----	NS (298)
Dissolved oxygen, mg/L	0.131	-0.025	0.015 (342)	0.107		NS (299)
Dissolved oxygen, percent saturation	0.056	-----	NS (342)	0.139	0.190	0.016 (299)
Secchi disk depth	0.611	1.40	<0.001 (338)	0.314	0.449	<0.001 (294)
Light attenuation coefficient	0.593	0.070	<0.001 (269)	0.093	-----	NS (239)
pH, Field	0.261	-0.015	<0.001 (287)	0.139	0.027	0.007 (254)
Chlorophyll, depth-integrated	0.622	-3.41	<0.001 (334)	0.338	-0.774	<0.001 (292)
Chlorophyll, surface	0.609	-3.43	<0.001 (353)	0.319	-0.850	<0.001 (306)

Numbers in parenthesis next to significance value indicate “n” = number of data points for each parameter for that station.

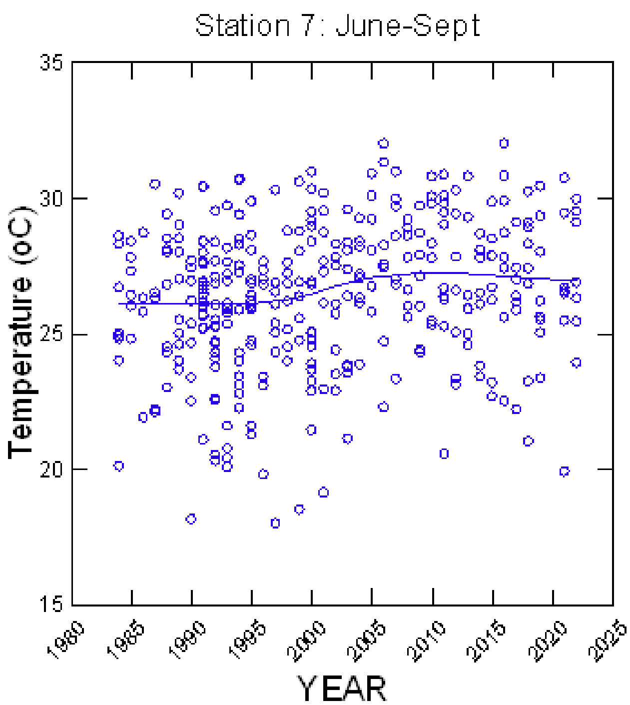
Significance column indicates the probability that a correlation coefficient this large could be due to chance alone. If this probability is greater than 0.05, then NS (not significant) is indicated. Both near surface and near bottom samples included.

Table 18
Correlation and Linear Regression Coefficients
Water Quality Parameter vs. Year for 1983-2022
Fairfax County Environmental Laboratory Data
June-September

	Station 7			Station 9		
Parameter	Corr. Coeff.	Reg. Coeff.	Signif.	Corr. Coeff.	Reg. Coeff.	Signif.
Chloride	0.011	-----	NS (545)	0.064	-----	NS (278)
Lab pH	0.580	-0.036	<0.001 (560)	0.408	-0.018	<0.001 (282)
Alkalinity	0.136	0.151	0.029 (549)	0.408	0.472	<0.001 (280)
BOD	0.636	-0.136	<0.001 (555)	0.441	-0.042	<0.001 (281)
Total Suspended Solids	0.347	-0.739	<0.001 (522)	0.194	-0.095	0.002 (259)
Volatile Suspended Solids	0.406	-0.494	<0.001 (519)	0.404	-0.113	<0.001 (258)
Total Phosphorus	0.567	-0.003	<0.001 (562)	0.368	-0.001	<0.001 (282)
Soluble Reactive Phosphorus	0.148	-0.0001	0.001 (546)	0.047	-----	NS (274)
Ammonia Nitrogen	0.328	-0.014	<0.001 (560)	0.270	-0.002	<0.001 (282)
Nitrite Nitrogen	0.456	-0.003	<0.001 (484)	0.174	-0.001	<0.001 (243)
Nitrate Nitrogen	0.608	-0.030	<0.001 (562)	0.631	-0.029	<0.001 (282)
Organic Nitrogen	0.608	-0.042	<0.001 (552)	0.403	-0.012	<0.001 (265)
N to P Ratio	0.296	-0.301	<0.001 (553)	0.282	-0.291	<0.001 (263)
Chlorophyll a				0.304	-1.056	<0.001 (173)

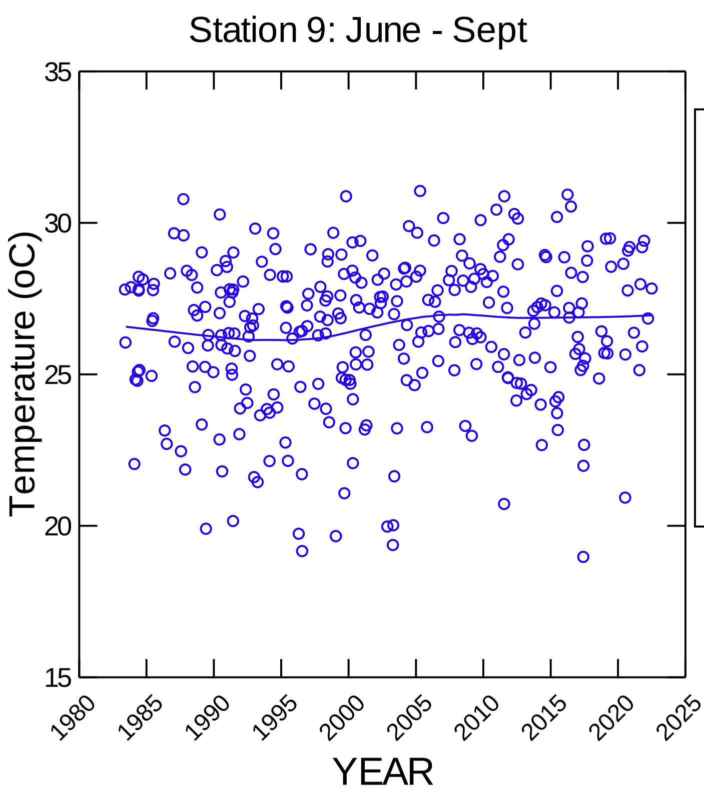
Numbers in parenthesis next to significance value indicate “n” = number of data points for each parameter for that station.

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.



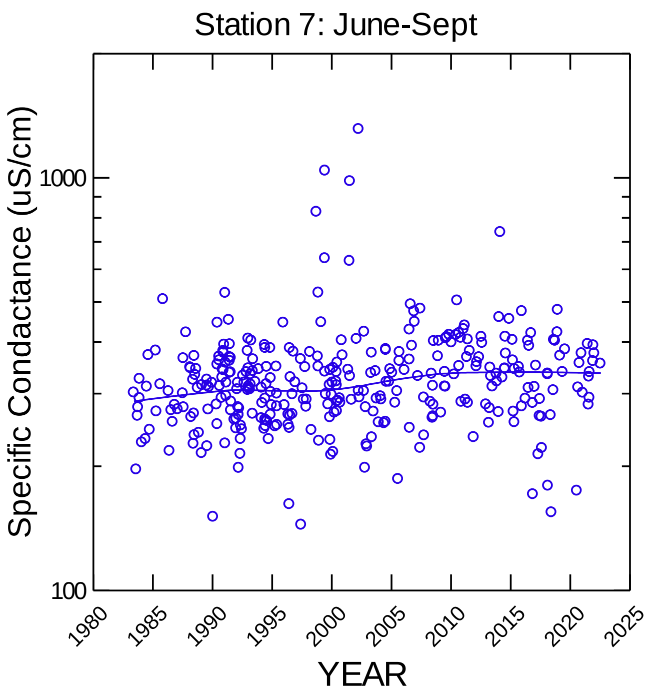
Water temperatures during the summer months generally varied between 20ºC and 30ºC over the study period (Figure 79). The LOWESS curve indicated an average of about 26°C during the period 1984-2001 with a slight upward trend in the last few years to about 27ºC. Linear regression analysis indicated a significant linear trend in water temperature in the cove when the entire period of record is considered (Table 17). The slope of this relationship is 0.05°C/year.

Figure 79. Long term trend in Water Temperature (GMU Field Data). Station 7. Gunston Cove.



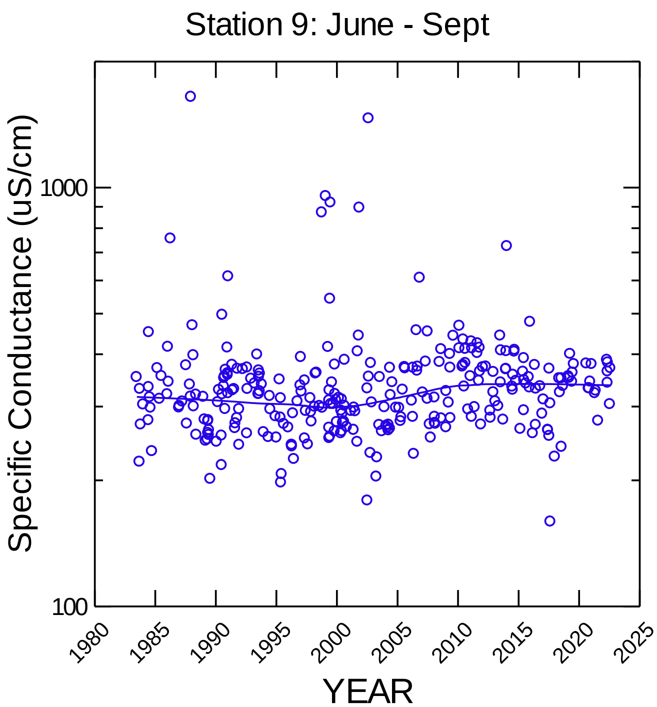
In the river summer temperatures have been similar to those in the cove with fewer readings above 30°C in the river (Figure 80). The long term trend is marginally significant with a slope of °C/year (Table 17).

Figure 80. Long term trend in Water Temperature (GMU Field Data). Station 9. Gunston Cove.



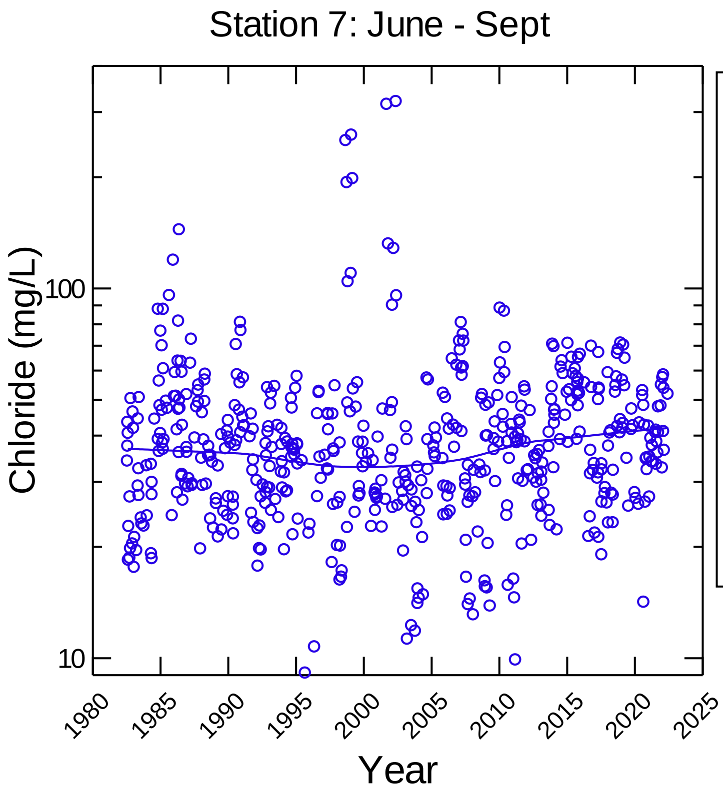
Specific conductance was generally in the range 200-500 µS/cm over the study period (Figure 81). Some significantly higher readings have been observed sporadically. A slight increase in specific conductance was suggested by the LOWESS line over the study period. This was significant over the study period with a slope of 1.3uS/cm/yr (Table 17).

Figure 81. Long term trend in Specific Conductance (GMU Field Data). Station 7. Gunston Cove.



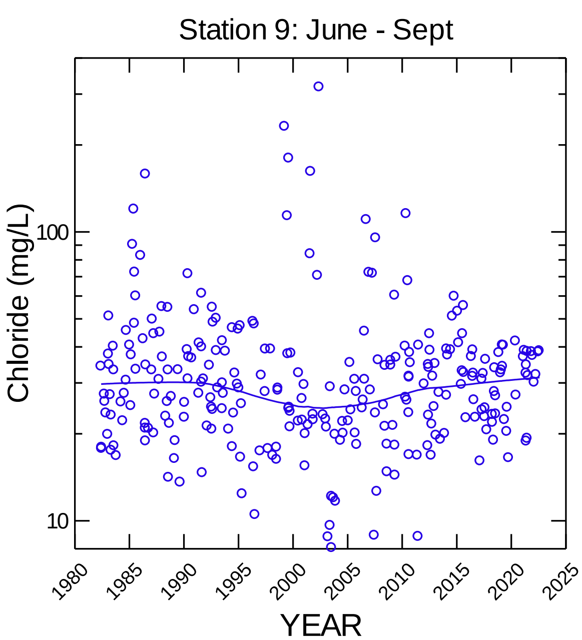
Conductivity values in the river were in the same general range as in the cove (Figure 82). Most values were between 200 and 500 µS/cm with a few much higher values. These higher values are probably attributable to intrusions of brackish water from downstream during years of low river flow. Linear regression did not reveal a significant trend in river conductivity (Table 17).

Figure 82. Long term trend in Specific Conductance (GMU Field Data). Station 9. River mainstem.



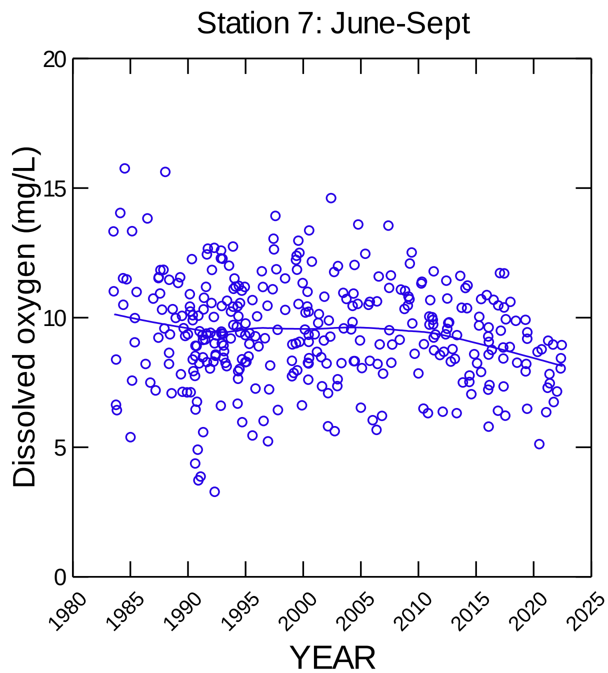
Chloride levels were clustered in a relatively narrow range of 20-70 mg/L for the entire study period (Figure 83). Higher values observed in some years were probably due to the estuarine water intrusions that occur in dry years. The trend line is nearly flat and a linear regression was not statistically significant (Table 18).

Figure 83. Long term trend in Chloride (Fairfax County Lab Data). Station 7. Gunston Cove.



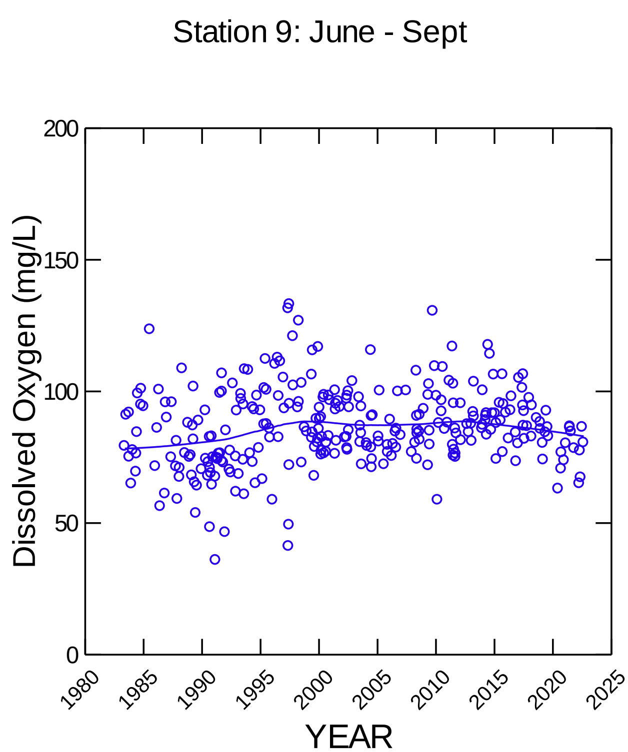
Chloride in the river has been slightly more variable than that in the cove, but in the same general range (Figure 84). The higher readings are again due to brackish water intrusions in dry years. A slight trend of increasing values in the 1980's followed by decreases in the 1990's and increases since 2005 was suggested by the LOWESS trend line. However, temporal linear regression analysis was not statistically significant (Table 18).

Figure 84. Long term trend in Chloride (Fairfax County Lab Data). Station 9. River mainstem.



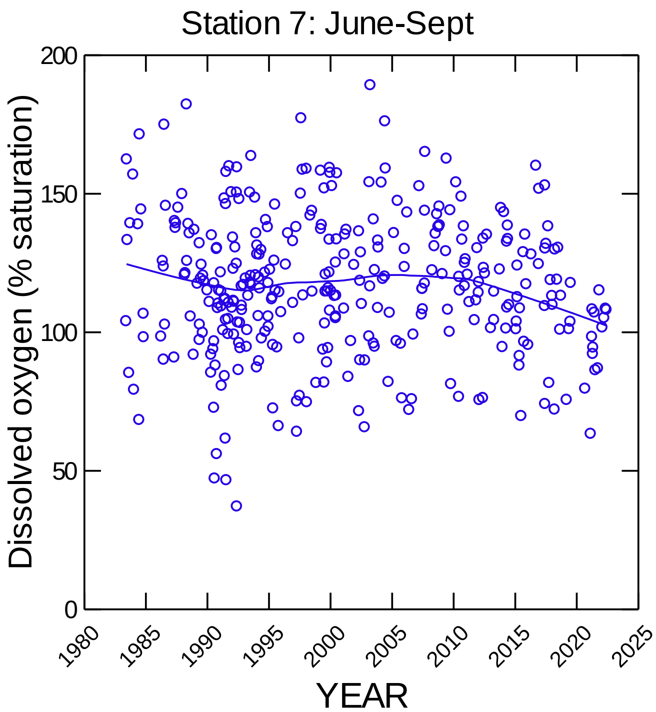
Dissolved oxygen in the cove has generally been in the range 7-13 mg/L during the summer months (Figure 85). A slight downward trend was observed through 1990, but since then the trend line has flattened, suggesting little consistent change and a mean of about 9 mg/L. In the cove dissolved oxygen (mg/L) exhibited a marginally significant downward trend -0.02 mg/L/yr (Table 17).

Figure 85. Long term trend in Dissolved Oxygen, mg/L (GMU Data). Station 7. Gunston Cove.



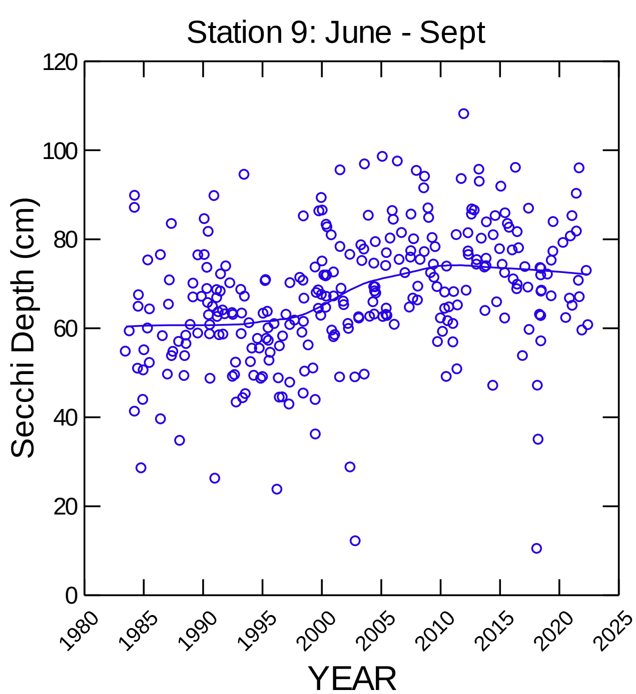
In the river dissolved oxygen values generally were in the range 5-9 mg/L over the long term study period (Figure 86). The LOWESS trend line some subtle changes from year to year, but little consistent pattern. The linear regression analysis over the entire period did not indicate a statistically significant change (Table 17).

Figure 86. Long term trend in Dissolved Oxygen, mg/L (GMU Data). Station 9. River mainstem.



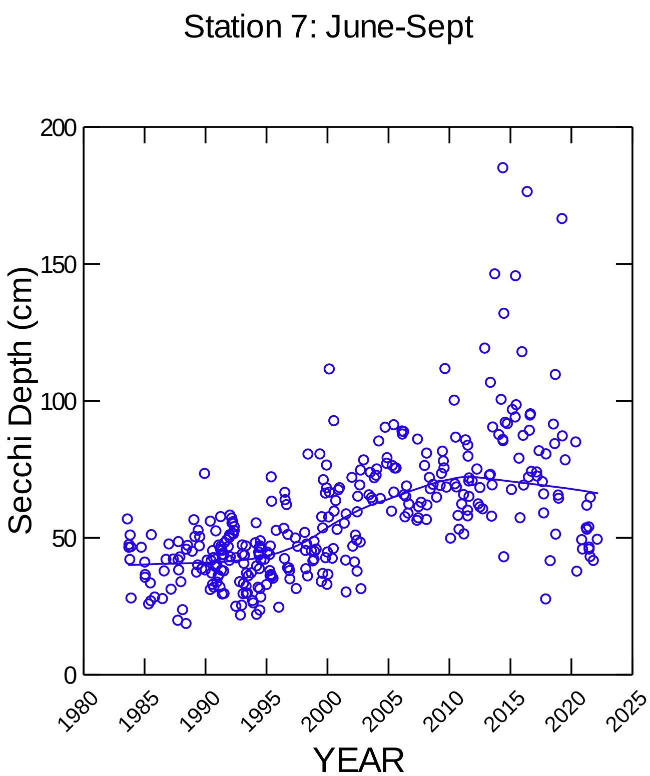
Dissolved oxygen was generally in the range 100-150% saturation in the cove over the long-term study period indicating the importance of photosynthesis in the cove (Figure 87). A decline was indicated by the trend line through 1990 followed by a slight recovery in subsequent years. Recently it has started to decrease again. Percent saturation DO did not exhibit a significant linear trend over the long-term study period (Table 17). 2022 values were generally below the trend line at less than 100% saturation.

Figure 87. Long term trend in Dissolved Oxygen, % saturation (GMU Data). Station 7. Gunston Cove.



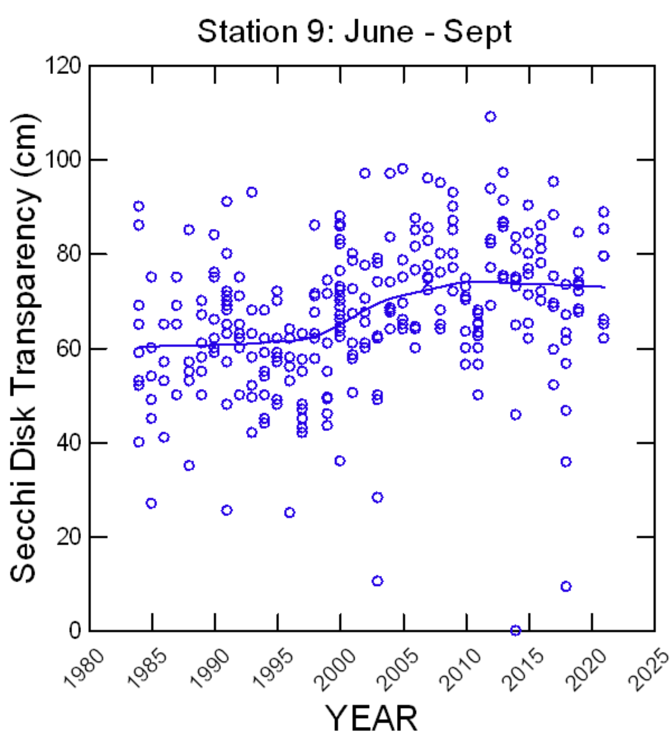
In the river dissolved oxygen was generally less than 100% indicating that photosynthesis was much less important in the river than in the cove and that respiration dominated (Figure 88). The trend line showed a very gradual increase which was statistically significant as indicated by regression analysis with a slope of 0.19% per year or about 11% over the course of the study (Table 17). Despite this increase river DO was still below cove DO in general.

Figure 88. Long term trend in Dissolved Oxygen, % saturation (GMU Data). Station 9. River Mainstem.



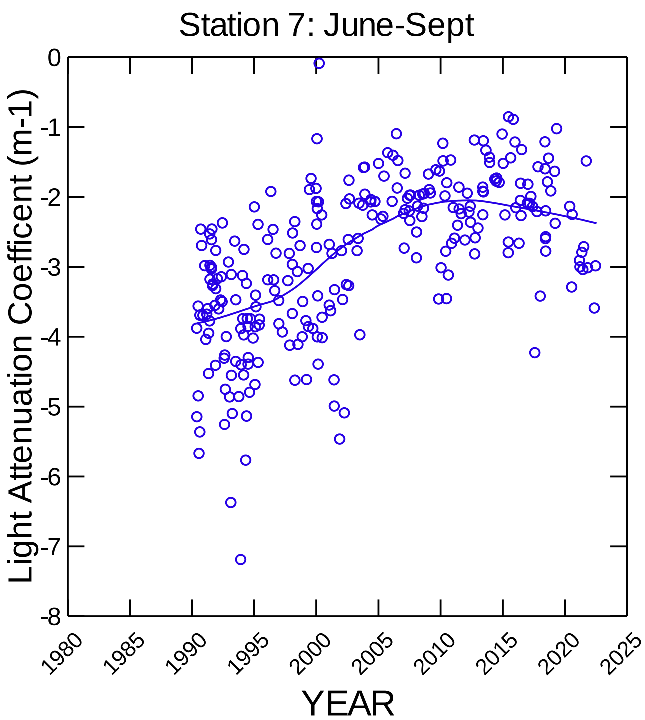
Secchi disk transparency is a measure of water clarity. Secchi disk was fairly constant from 1984 through 1995 with the trend line at about 40 cm (Figure 89). Since 1995 there has been a steady increase in the trend line from 40 cm to 80 cm although it is showing signs of decreasing. .Linear regression was highly significant with a predicted increase of 1.4 cm per year or a increase of 56 cm over the study period (Table 17).

Figure 89. Long term trend in Secchi Disk Transparency (GMU Data). Station 7. Gunston Cove.



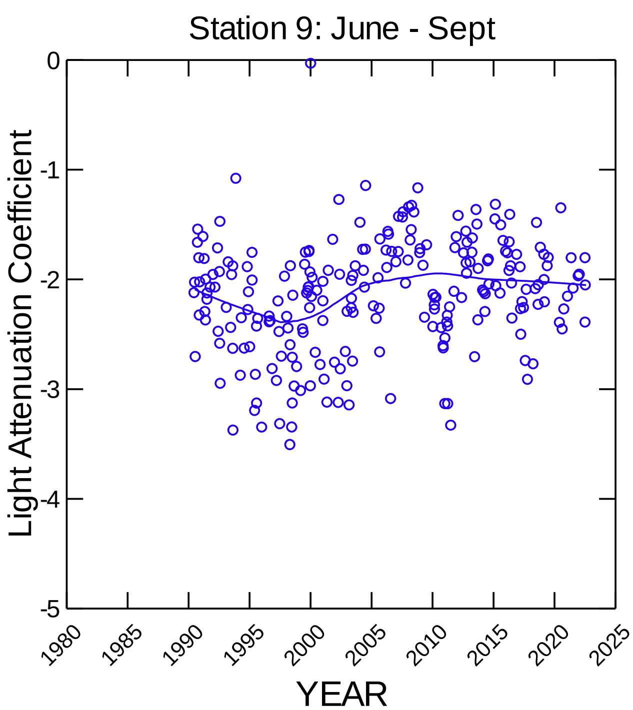
In the river Secchi depth was somewhat greater than in the cove in the 1980's (Figure 90). The trend line was fairly constant at about 60 cm until about 2000. A rise to about 75 cm was observed by 2005 where it has remained. Linear regression revealed a significant increase of 0.45 cm per year with total increase of 18 cm predicted over of the study period (Table 17). Observations in 2022 straddled the trend line.

Figure 90. Long term trend in Secchi Disk Transparency (GMU Data). Station 9. River mainstem.



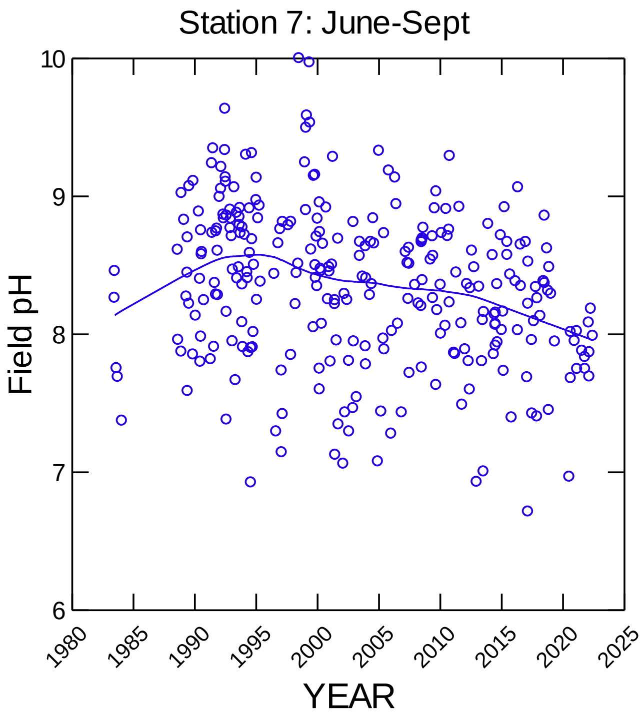
Light attenuation coefficient, another measure of water clarity, reinforces the conclusion that water clarity has been improving in the cove since 1995 (Figure 91). Trend line for the coefficient rose from about -4 to -2 m^{-1} during this time, but has recently declined to about -2.5. Regression analysis revealed a significant linear increase in light attenuation coefficient over the period 1991-2022 with a slope of 0.07 per year yielding a prediction that light attenuation improved by about 2.2 units over this period (Table 17).

Figure 91. Long term trend in Light Attenuation Coefficient (GMU Data). Station 7. Gunston Cove.



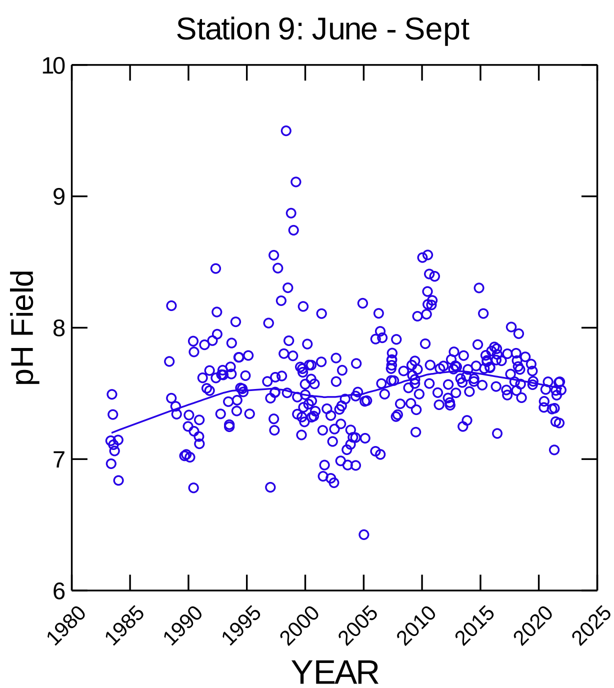
In the river light attenuation coefficient suggested a decline in light transparency between 1991 and 1997 followed by an increase through about 2008 (Figure 92). Between 2008 and 2022 the trend line indicates that light transparency has held fairly constant. Regression did not produce a significant slope over the period (Table 17).

Figure 92. Long term trend in Light Attenuation Coefficient (GMU Data). Station 9. River mainstem.



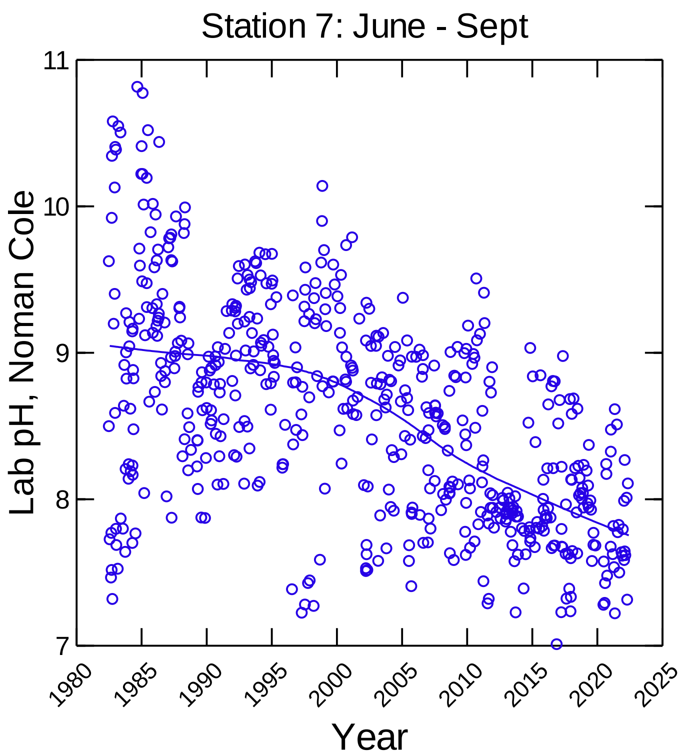
Field pH has not been measured as consistently over the entire study period as other parameters. Cove values have generally been in the 8-9 range. There is a clear trend of decreasing values since 1995 (Figure 93). Linear regression analysis now gives evidence of a declining linear trend with a slope of -0.015 units per year when the entire study period was considered (Table 17).

Figure 93. Long term trend in Field pH (GMU Data). Station 7. Gunston Cove.



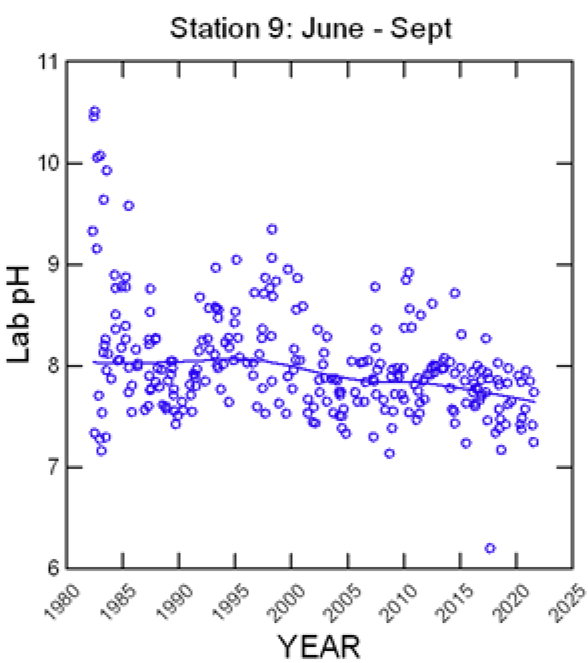
In the river a different pattern has been observed over this period (Figure 94). pH in the river has been consistently lower by about 1 pH unit than in the cove. If anything, the trend line has shown a tendency to increase. When all years were considered, field pH in the river shows a significant increase at a rate of 0.027 units per year (Table 17).

Figure 94. Long term trend in Field pH (GMU Data). Station 9. River mainstem.



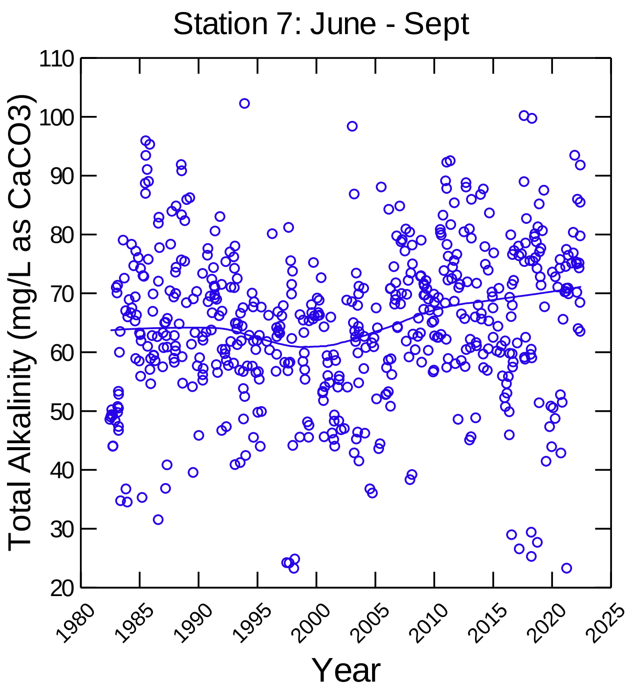
Lab pH as measured by Fairfax County personnel has shown a clear decline, especially since 2000 (Figure 95) with the trend line decreasing from about 9.0 to about 7.8. Linear regression indicates a significant decline in lab pH over the study period at a rate of about 0.036 pH units per year or a total of 1.4 units over the study period (Table 18). 2022 data were generally near the trend line.

Figure 95. Long term trend in Lab pH (Fairfax County Lab Data). Station 7. Gunston Cove.



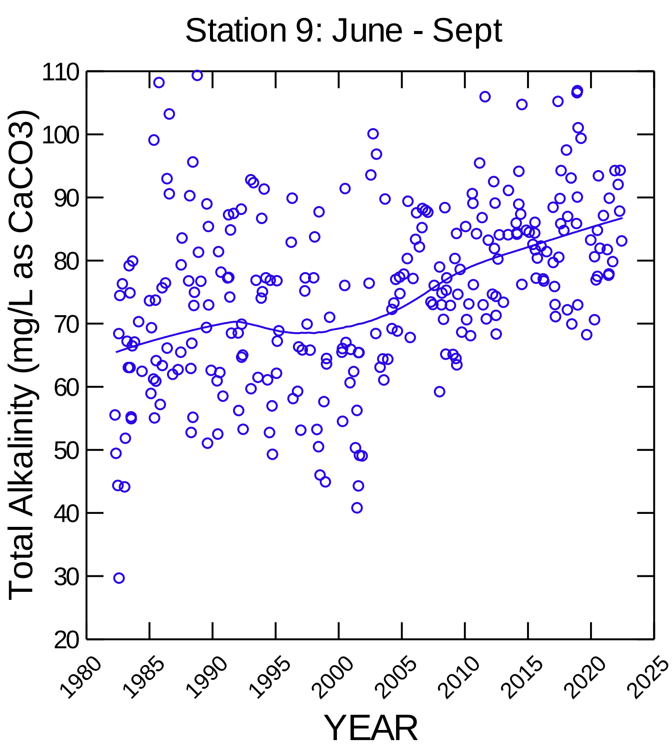
In the river, long term pH trends as measured by Fairfax County lab personnel indicate that most values fell between 7.2 and 8.2 (Figure 96). The trend line has increased and decreased slightly over the years. pH in the river showed a significant linear decline with a rate of 0.018 per year yielding a total decline of 0.72 units over the long-term study period (Table 18).

Figure 96. Long term trend in Lab pH (Fairfax County Lab Data). Station 9. Potomac mainstem.



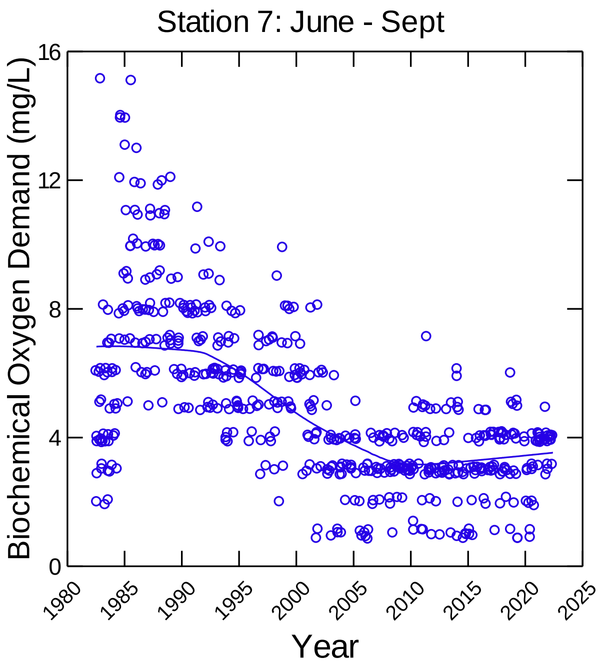
Total alkalinity as measured by Fairfax County personnel exhibited little variation early on, a slow increase until 2010 and little change since (Figure 97). The trend line at 2022 was slightly higher than it was in 1983. Overall, a very weak statistically significant linear trend has developed in total alkalinity in the cove over this period with a slope of 0.15 mg/L per year yielding a projected increase of about 6 mg/L over the entire study period (Table 18).

Figure 97. Long term trend in Total Alkalinity (Fairfax County Lab Data). Station 7. Gunston Cove.



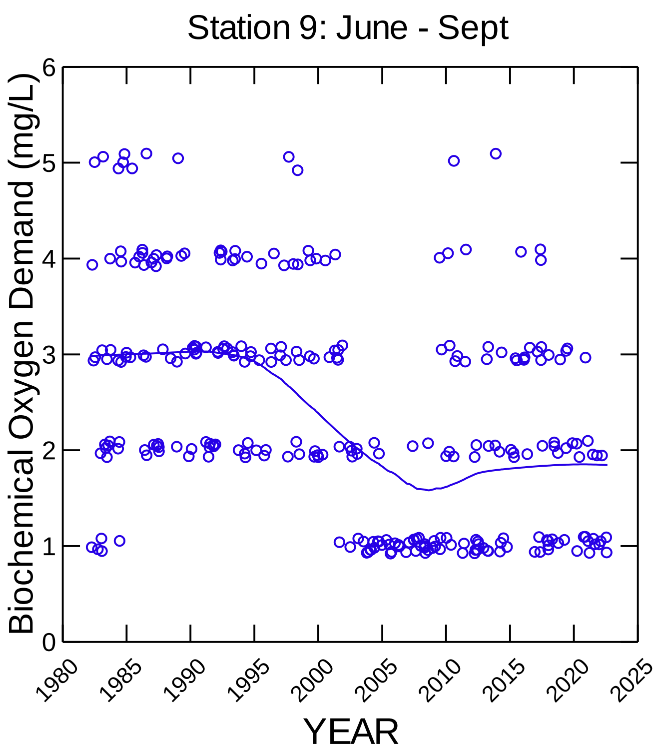
In the river a similar pattern has been observed over the three decades with an even clearer recent increase (Figure 98). There is a significant linear trend over the period with a slope of 0.47 mg/L suggesting an increase of about 19 mg/L over the entire study period (Table 18).

Figure 98. Long term trend in Total Alkalinity (Fairfax County Lab Data). Station 9. Potomac mainstem.



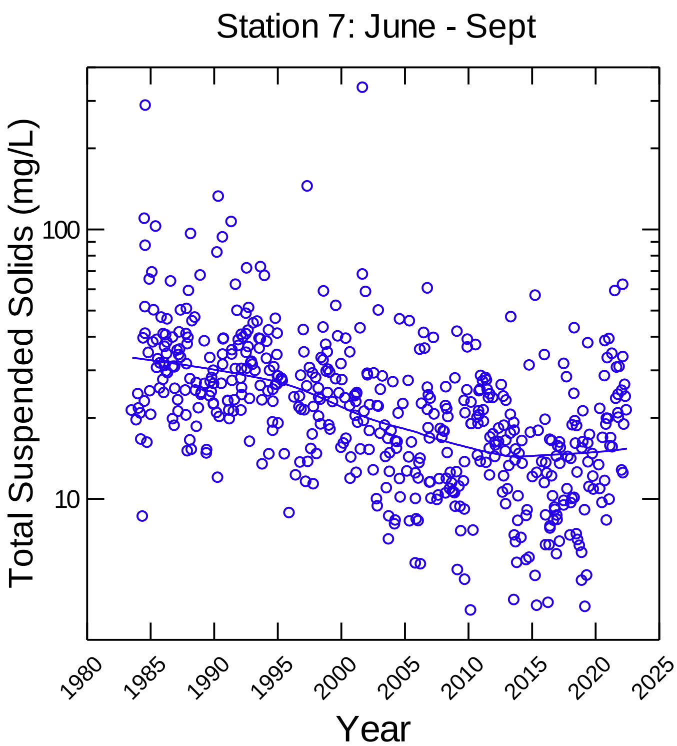
Biochemical oxygen demand has shown a distinct pattern over the long-term study period in Gunston Cove (Figure 99). In the 1980's the trend line rose from about 6 mg/L to 7 mg/L by 1989. Since then there has been a steady decline such that the trend line has dropped back to about 3 mg/L. BOD has shown a significant linear decline over the entire study period at a rate of 0.14 mg/L per year yielding a net decline of about 5.3 mg/L over the entire period of record (Table 18). It is difficult to tell if the decline is continuing as many readings are now below the detection limit.

Figure 99. Long term trend in Biochemical Oxygen Demand (Fairfax County Lab Data). Station 7. Gunston Cove.



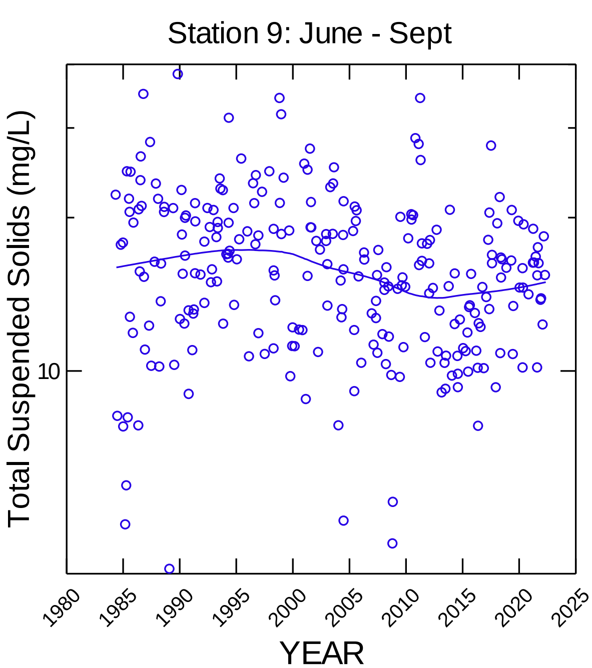
In the river biochemical oxygen demand exhibited a less distinct pattern through the mid 1990's (Figure 100). However, since that time it has decreased somewhat to a trend line value of about 2.0 mg/L. BOD in the river has exhibited a significant linear decrease at a rate of 0.04 units when the entire period of record was considered (Table 18). This would project to an overall decrease of 1.5 units. Many values now are non- detects of less than 2 mg/L making trends difficulty to examine.

Figure 100. Long term trend in Biochemical Oxygen Demand (Fairfax County Lab Data). Station 9. Potomac mainstem.



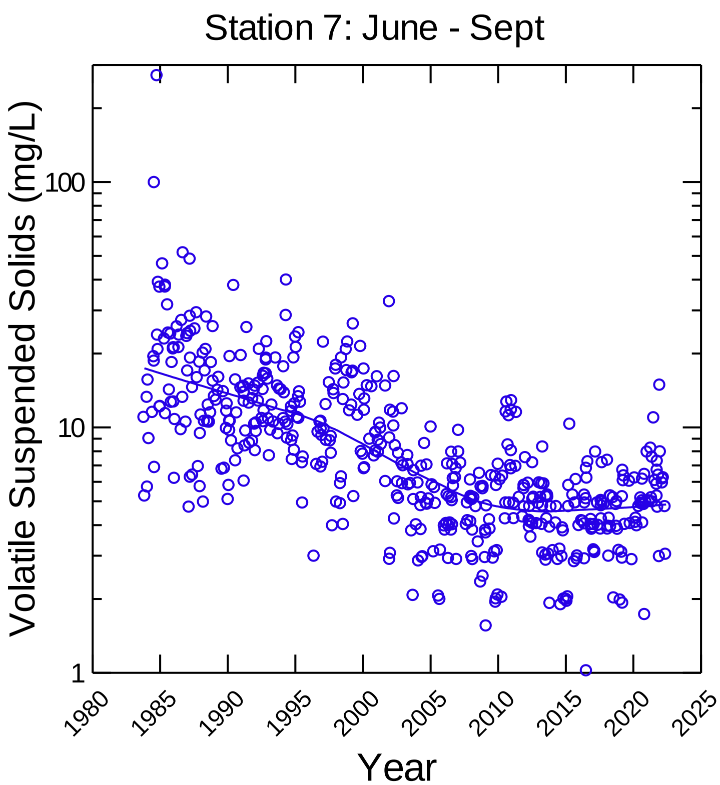
Total suspended solids (TSS) has shown a great deal of variability over the long-term study period. Nonetheless, a decreasing trend in TSS is clear in the cove with the trend line decreasing from about 32 mg/L in 1983 to about 10 mg/L in 2021 (Figure 101). Values in 2022 were above the trend line and increased it slightly. Linear regression was significant indicating a decline of 0.74 mg/L per year yielding a total decline of 31 mg/L since 1984 (Table 18).

Figure 101. Long term trend in Total Suspended Solids (Fairfax County Lab Data). Station 7. Gunston Cove.



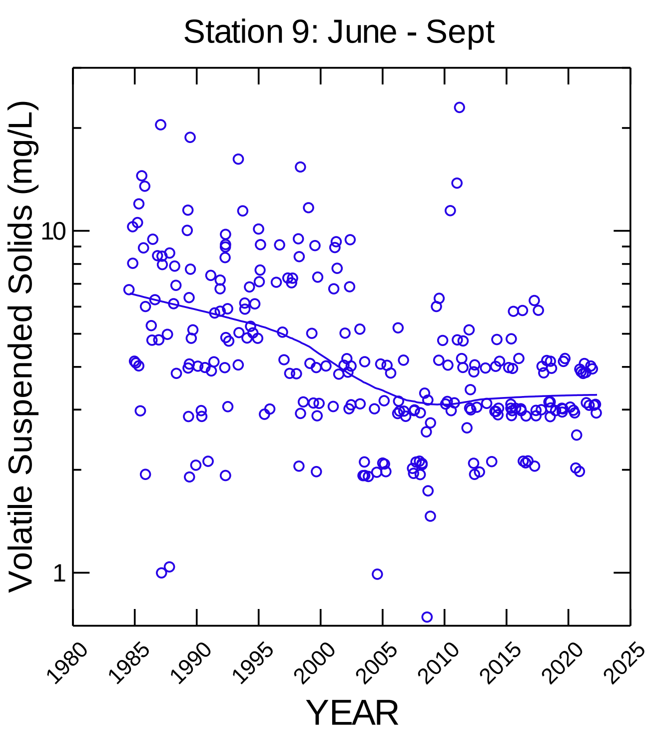
In the river TSS trends have not been as apparent (Figure 102). While much higher values have been observed sporadically, the LOWESS line remained steady at about 18-20 mg/L through most of the period with a slight decrease to about 15 mg/L suggested recently. In the river TSS exhibited a significant linear decline over the period of record at a rate of about 0.09 units per year yielding a total decline of about 4 mg/L over the entire study period (Table 18).

Figure 102. Long term trend in Total Suspended Solids (Fairfax County Lab Data). Station 9. Potomac mainstem.



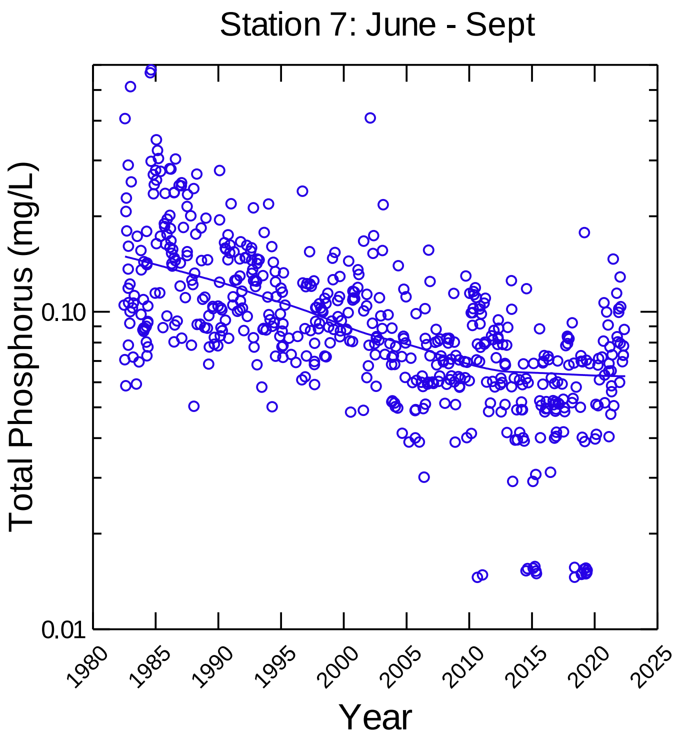
Volatile suspended solids have consistently declined over the study period in the cove (Figure 103). The LOWESS trend line has declined from 20 mg/L in 1984 to about 5 mg/L in 2022. VSS has demonstrated a significant linear decline at a rate of 0.5 mg/L per year or a total of 20 mg/L over the study period (Table 18).

Figure 103. Long term trend in Volatile Suspended Solids (Fairfax County Lab Data). Station 7. Gunston Cove.



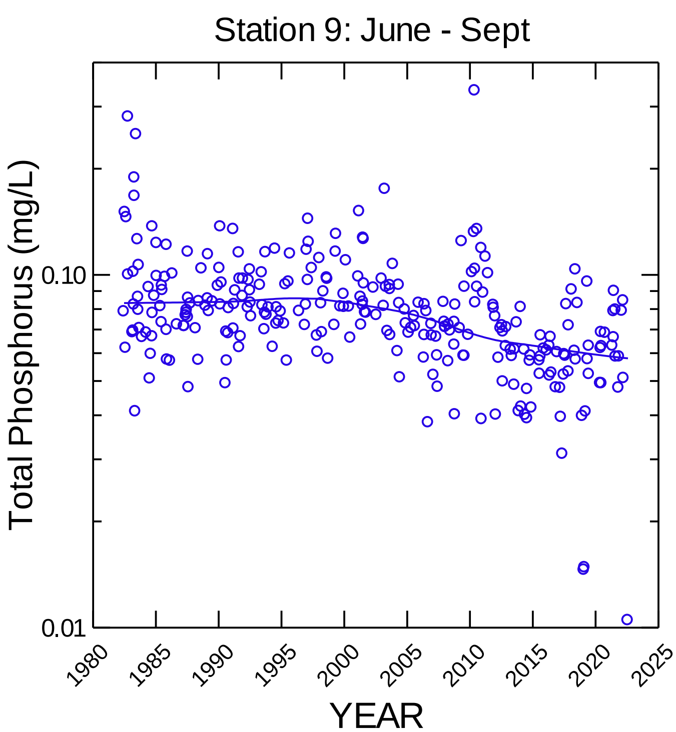
In the river the trend line for volatile suspended solids (VSS) was steady from 1984 through the mid 1990’s, but decreased from 1995 to 2005. Trend line values of about 7 mg/L in 1984 dropped to about 3.5 mg/L by 2022 (Figure 104). VSS in the river demonstrated a significant linear decline at a rate of 0.11 mg/L per year or 4 mg/L since 1984 (Table 18).

Figure 104. Long term trend in Volatile Suspended Solids (Fairfax County Lab Data). Station 9. Potomac mainstem.



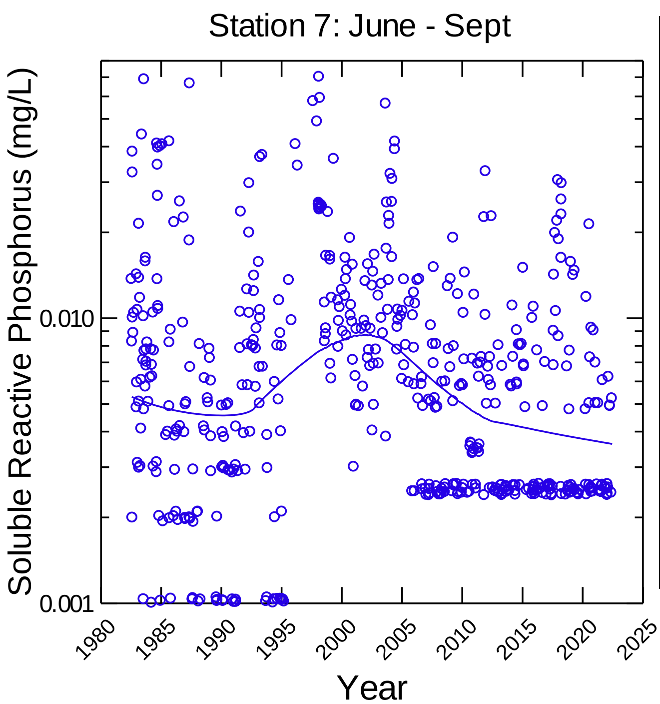
In the cove, total phosphorus (TP) has undergone a consistent steady decline since the late 1980's (Figure 105). By 2021 the trend line had dropped to 0.06 mg/L, less than half of the starting level. Linear regression over the entire period of record indicated a significant linear decline of -0.003 mg/L per year or 0.12 mg/L over the entire study period (Table 18).

Figure 105. Long term trend in Total Phosphorus (Fairfax County Lab Data). Station 7. Gunston Cove.



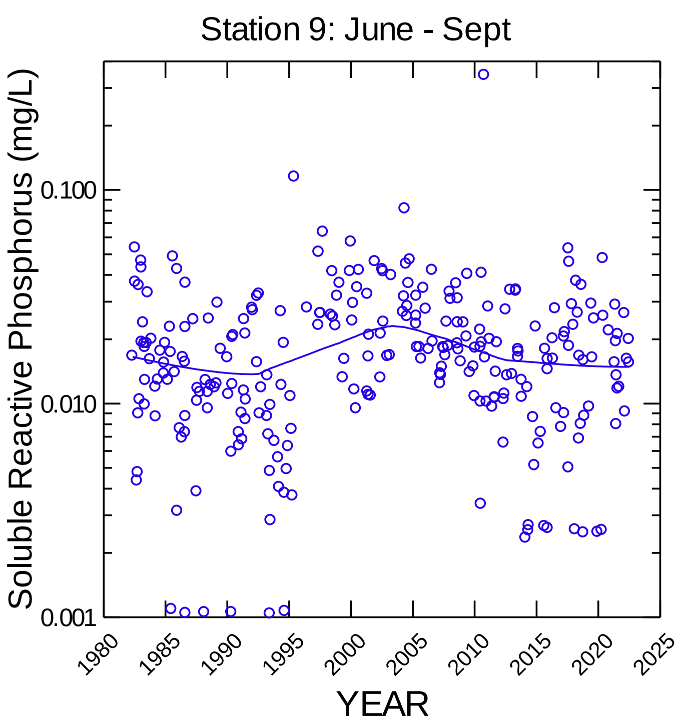
Total phosphorus (TP) values in the river have shown less of a trend over time (Figure 106). Values were steady through about 2000, then declined somewhat. TP exhibited a slight, but significant linear decrease in the river over the long-term study period with a very modest slope of -0.001 mg/L per year for a cumulative decrease of 0.04 mg/L over the period (Table 18).

Figure 106. Long term trend in Total Phosphorus (Fairfax County Lab Data). Station 9. Potomac mainstem.



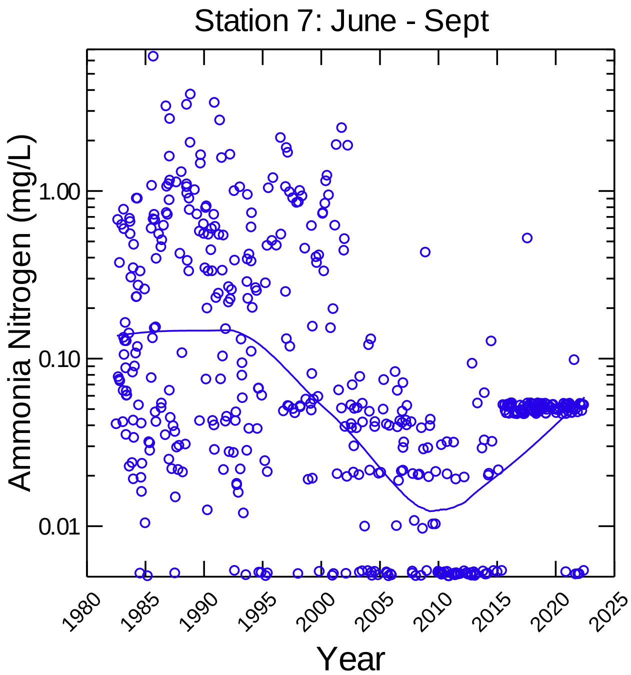
Soluble reactive phosphorus (SRP) declined in the cove during the first few years of the long-term data set, but demonstrated an increase to near its initial level by 2000 (Figure 107). Since then a decline has ensued. (Table 18). One possibility is that less SRP is entering the cove water; another is that increased SAV is taking more up. Note also that the detection limit has changed and that many readings are at the detection limit making trend analysis difficult and uncertain.

Figure 107. Long term trend in Soluble Reactive Phosphorus (Fairfax County Lab Data). Station 7. Gunston Cove.



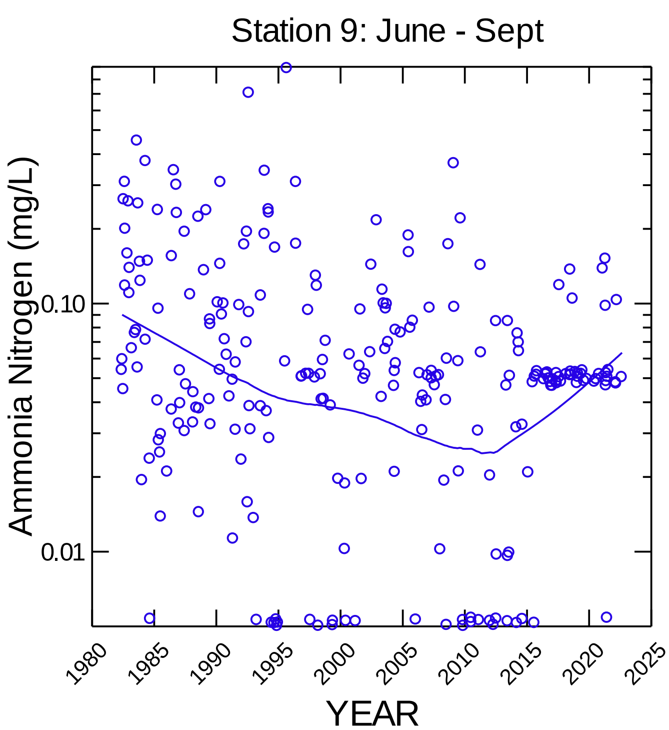
Soluble reactive phosphorus (SRP) in the river has generally been present at higher levels than in the cove, but has undergone a similar decline-resurgence-decline (Figure 108). Linear regression was not significant (Table 18). There were a significant number of non-detect values, but fewer than in the cove.

Figure 108. Long term trend in Soluble Reactive Phosphorus (Fairfax County Lab Data). Station 9. Potomac mainstem.



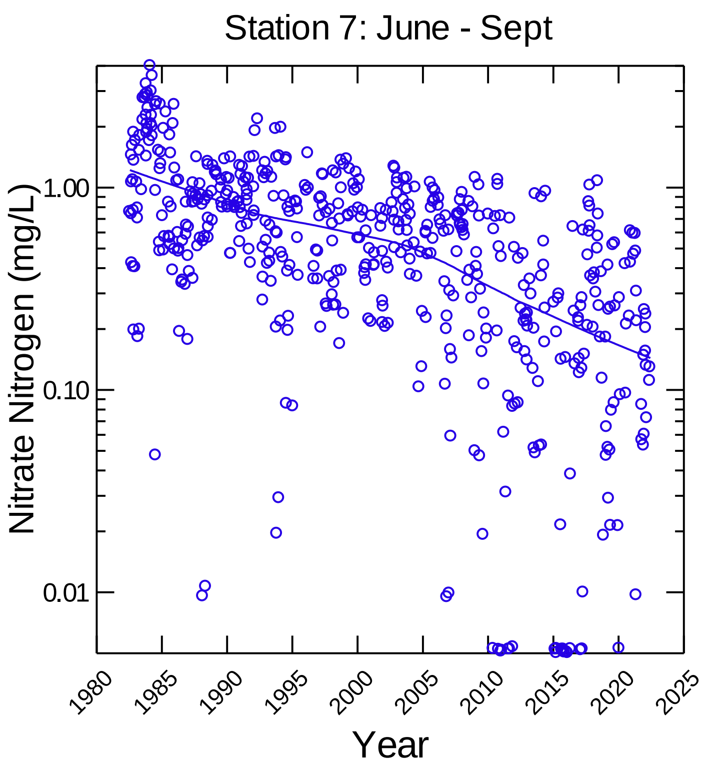
Ammonia nitrogen levels were very variable over the long term study period in the cove, but a trend of decreasing values is evident from the LOWESS trend line (Figure 109). Since 1989 the trend line decreased from about 0.2 mg/L to about 0.02 mg/L. However, the trend line has increased since 2015 due to an increase in the detection limits (Table 18). 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 109. Long term trend in Ammonia Nitrogen (Fairfax County Lab Data). Station 7. Gunston Cove.



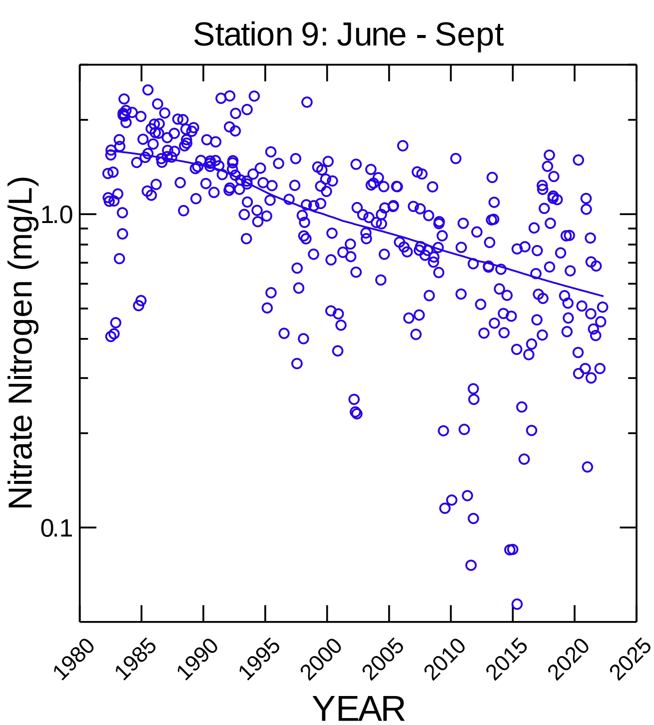
In the river a decreasing trend in ammonia nitrogen has also been observed over most of the study period (Figure 110). Between 1983 and 1999 the trend line dropped from 0.1 mg/L to 0.04 mg/L. Since 1999 it has continued to decline and is now at about 0.02 mg/L. Overall, in the river ammonia nitrogen has demonstrated a significant decline over the study period at a rate of 0.002 mg/L per year or a total of 0.07 over the study period (Table 18). Again, the number of non-detects is increasing and making it impossible to track future trends.

Figure 110. Long term trend in Ammonia Nitrogen (Fairfax County Lab Data). Station 9. Potomac mainstem.



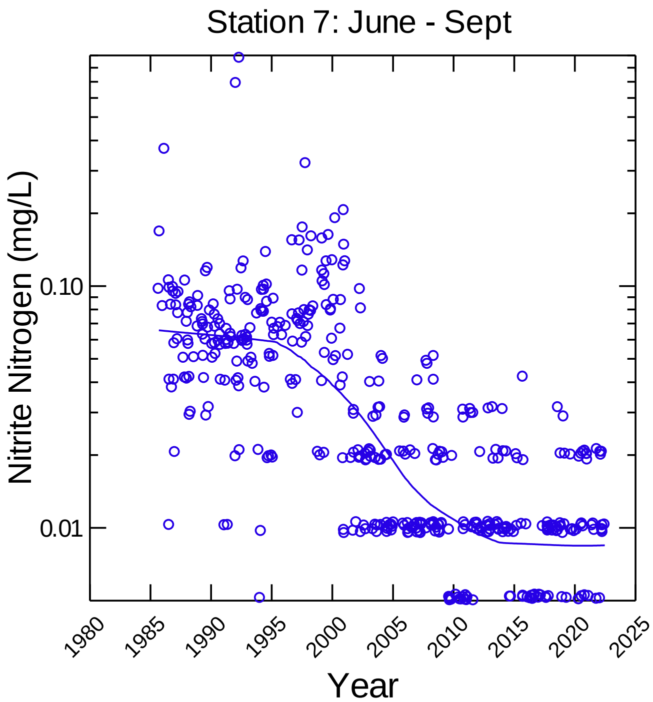
Nitrate nitrogen has demonstrated a steady decline in the cove over the entire period of record (Figure 111). The trend line was at about 1 mg/L in 1983 and by 2022 was below 0.15 mg/L. Linear regression suggested a decline rate of 0.030 mg/L per year yielding a total decline of 1.2 mg/L over the long-term study period (Table 18).

Figure 111. Long term trend in Nitrate Nitrogen (Fairfax County Lab Data). Station 7. Gunston Cove.



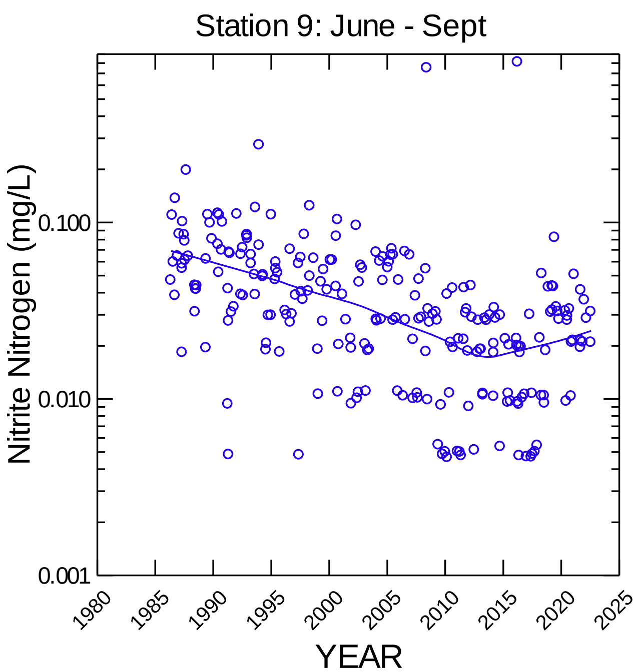
In the river nitrate nitrogen has declined steadily since about 1985 (Figure 112). The trend line dropped from 1.5 mg/L in the mid 1980's to 0.6 mg/L in 2020. Linear regression indicated a rate of decline of 0.029 mg/L per yr which would yield a 1.1 mg/L decrease in nitrate nitrogen over the study period (Table 18).

Figure 112. Long term trend in Nitrate Nitrogen (Fairfax County Lab Data). Station 9. River mainstem.



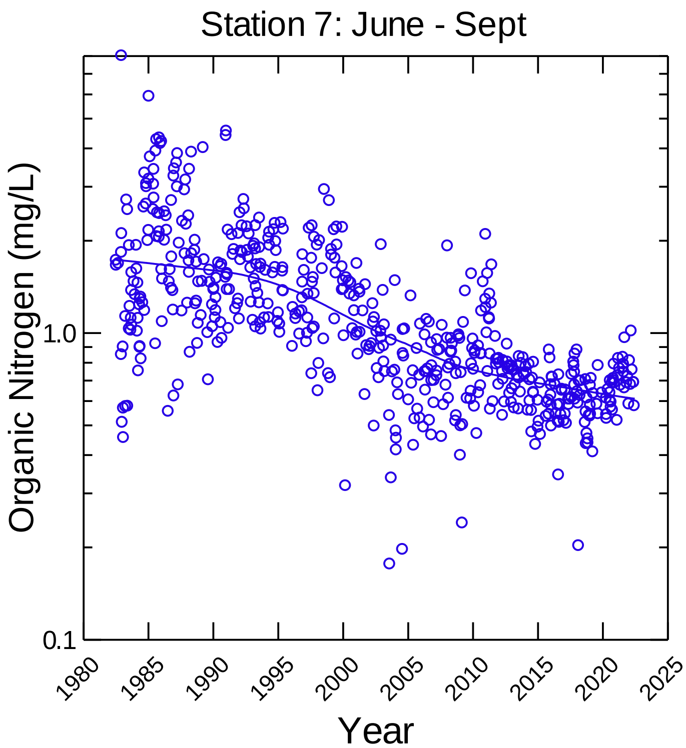
The trend line for nitrite nitrogen indicated steady values at about 0.06-0.07 mg/L through 1999 (Figure 113). Since then there is clear evidence for a decline with the LOWESS line dropping below 0.01 in 2013. Linear regression revealed a significant decline with a slope of 0.003 mg/L per year when the entire period of record was considered (Table 18). Most values in recent years have been at or below the detection limits meaning that further decreases will not be dectected.

Figure 113. Long term trend in Nitrite Nitrogen (Fairfax County Lab Data). Station 7. Gunston Cove.



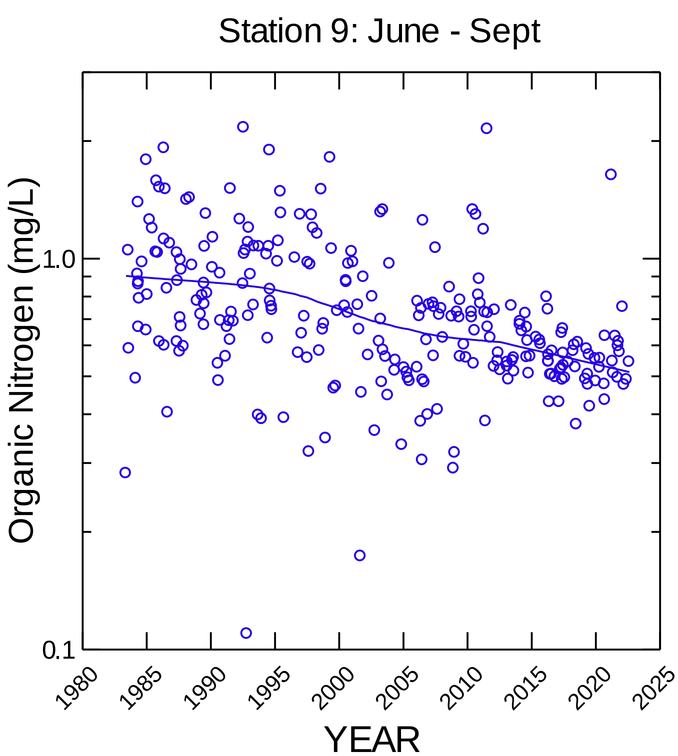
Nitrite nitrogen in the river demonstrated a pattern of decrease during the long term study period (Figure 114). The LOWESS line dropped from 0.07 mg/L in 1986 to less than 0.01 mg/L in 2018. Linear regression indicated a significant linear decline at a rate of 0.001 mg/L per year or 0.04 mg/L over the study period (Table 18). There has been a slight increase since 2019.

Figure 114. Long term trend in Nitrite Nitrogen (Fairfax County Lab Data). Station 9. Potomac mainstem.



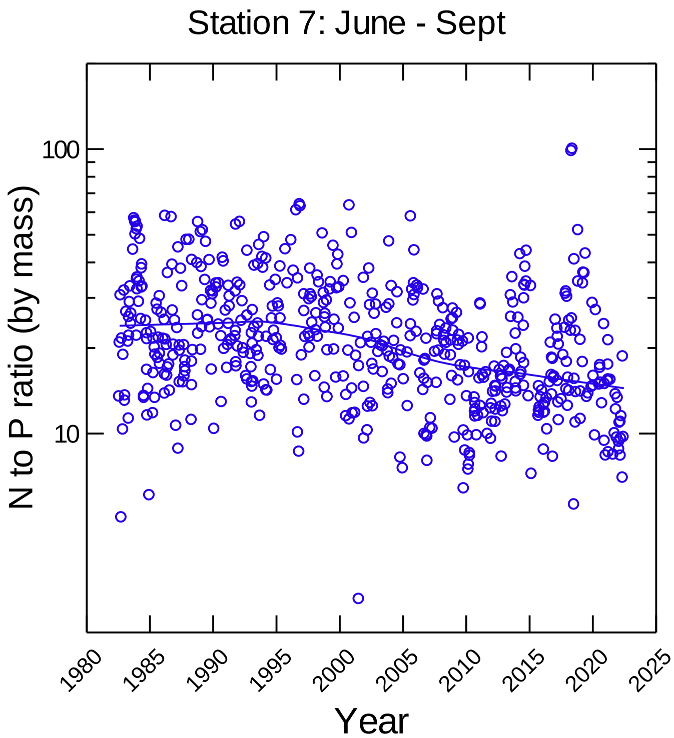
Organic nitrogen in the cove was fairly high in the 1980's and has since undergone a consistent decline through 2021 (Figure 115). In 1983 the trend line was at 1.5 mg/L and dropped below 0.6 mg/L by 2022. Regression analysis indicated a significant decline over the study period at a rate of about 0.042 mg/L per year or a total of 1.6 mg/L over the whole study period (Table 18).

Figure 115. Long term trend in Organic Nitrogen (Fairfax County Lab Data). Station 7. Gunston Cove.



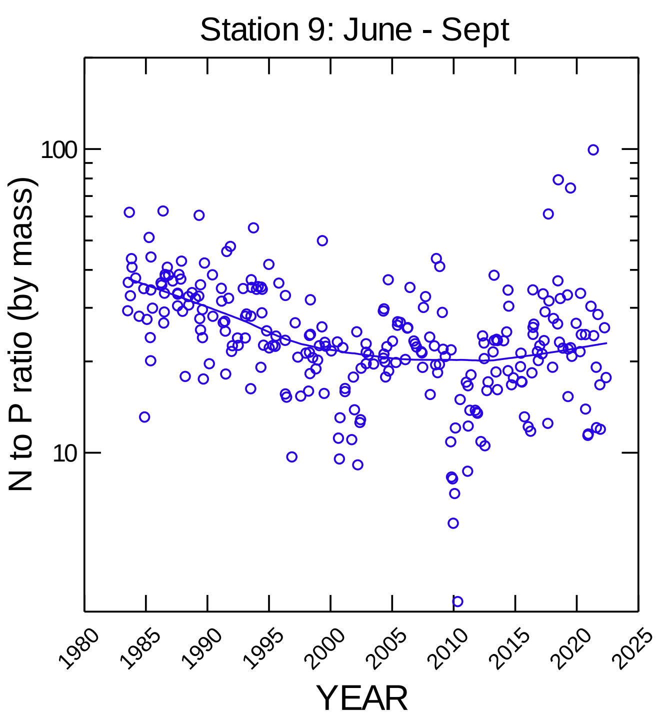
In the river organic nitrogen was steady from 1984 through 1995 and since then has shown perhaps a modest decline (Figure 116). The LOWESS line peaked at about 0.9 mg/L and has dropped to about 0.5 mg/L. Regression analysis indicated a significant linear decline at a rate of 0.01 mg/L when the entire period of record was considered for a total decline of 0.4 mg/L (Table 18).

Figure 116. 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 18 by 2022 (Figure 117). Regression analysis over the period of record indicates a statistically significant decline at a rate of 0.3 per year or about 12 units over the entire period (Table 18). This ratio is calculated using nitrate, TKN, and TP values and is less accurate when any of those are below detection limits.

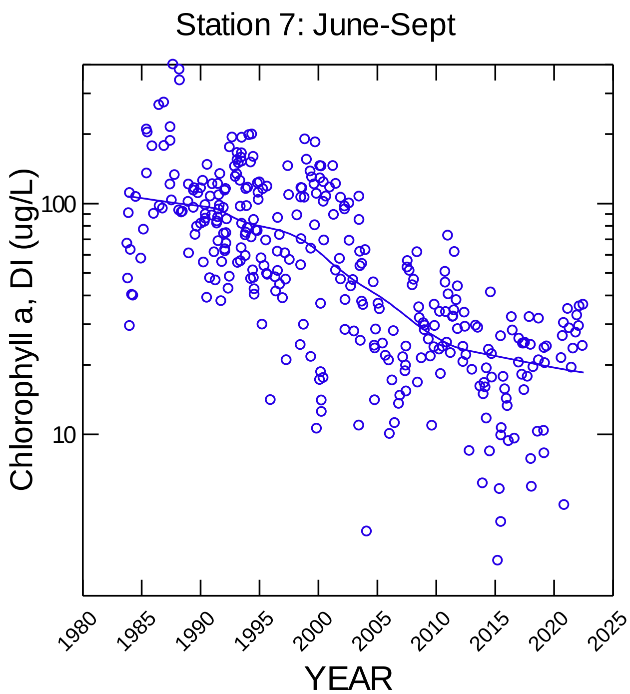
Figure 117. Long term trend in N to P Ratio (Fairfax County Lab Data). Station 7. Gunston Cove.



Nitrogen to phosphorus ratio in the river exhibited a strong continuous decline through about 2000 and has declined more slowly since then (Figure 118). 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 0.34 units per year or a total of 12 units over the long term study period (Table 18).

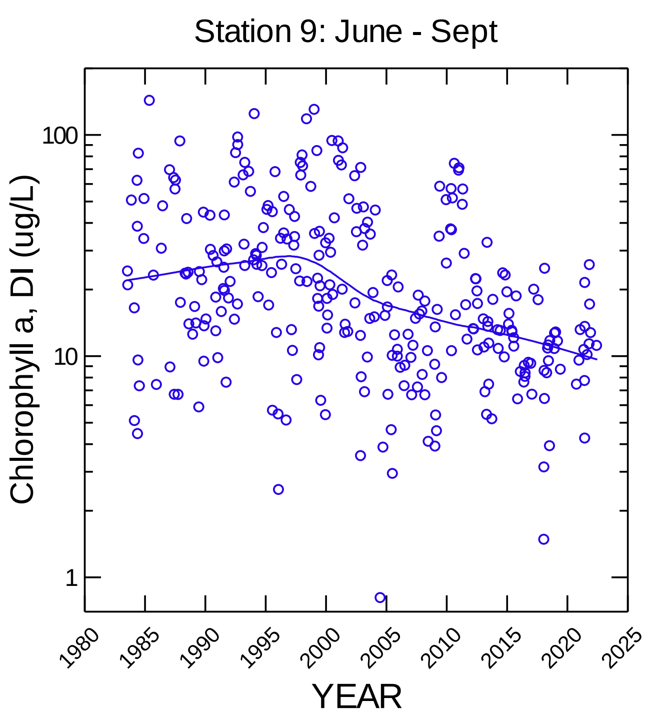
Figure 118. Long term trend in N to P Ratio (Fairfax County Lab Data). Station 9. River mainstem.

C. Phytoplankton Trends: 1984-2022



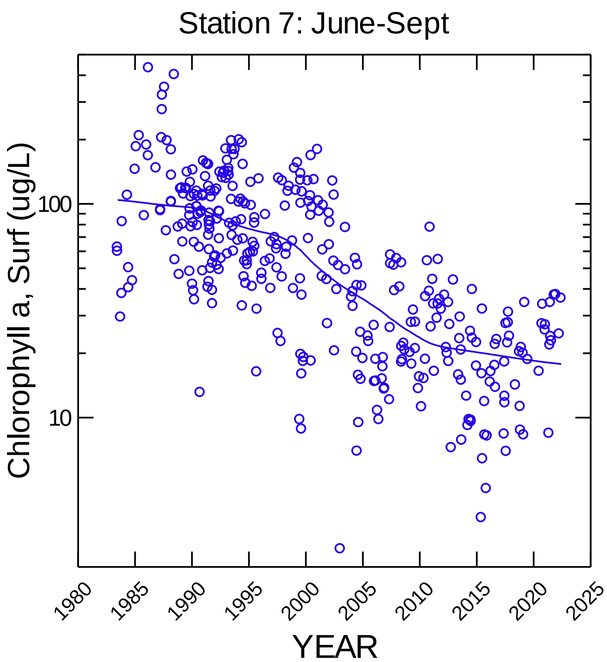
After increasing through much of the 1980's, depth-integrated chlorophyll *a* in the cove demonstrated a gradual decline from 1988 to 2000 and a much stronger decrease since then (Figure 119). The LOWESS line has declined from about 100 µg/L to about 20 µg/L in 2022. The observed decrease has resulted 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 3.4 µg/L per year or 130 µg/L over the 35-year long term data set (Table 17).

Figure 119. Long term trend in Depth-integrated Chlorophyll *a* (GMU Lab Data). Station 7. Gunston Cove.



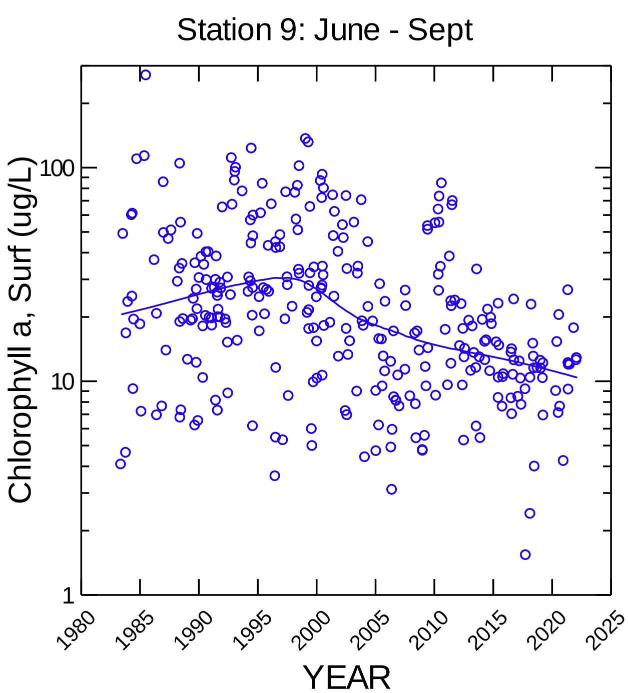
In the river depth-integrated chlorophyll *a* increased gradually through 2000 with the trend line rising from 20 to 30 µg/L (Figure 120). This was followed by a strong decline reaching about 9 µg/L by 2022. Regression analysis revealed a significant linear decline at a rate of 0.78 µg/L/yr when the entire period is considered (Table 17) yielding a total decline of about 30 ug/L.

Figure 120. 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 121). Trend line values of about 100 µg/L in 1988 dropped to about 20 µg/L in 2022. Linear regression confirmed the linear decline and suggested a rate of 3.6 µg/L per year or 130 µg/L over the entire study (Table 17).

Figure 121. 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 2022 (Figure 122). Values have stabilized since then at about 10 µg/L. Linear regression revealed a significant decline in surface chlorophyll across this period with a rate of 0.85 µg/L/yr or about 30 µg/L over the whole period (Table 17).

Figure 122. Long term trend in Surface Chlorophyll *a* (GMU Data). Station 9. River mainstem.

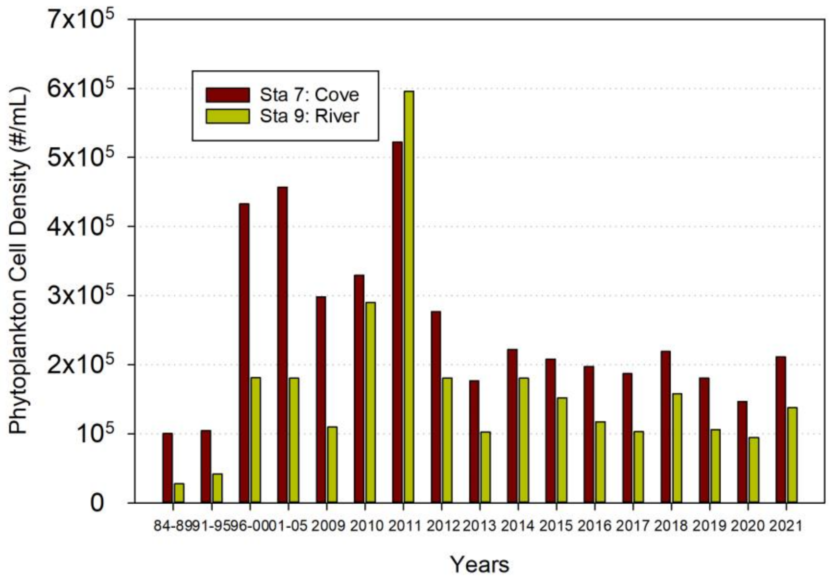


Figure 123. Interannual Comparison of Phytoplankton Density by Region.

Phytoplankton cell density in both the cove and the river in 2021 was similar to values observed since 2012 (Figure 123). While cell density does not incorporate cell size, it does provide some measure of the abundance of phytoplankton and reflects the decrease in phytoplankton in the study area which is expected with lower nutrient loading and should help improve water clarity.

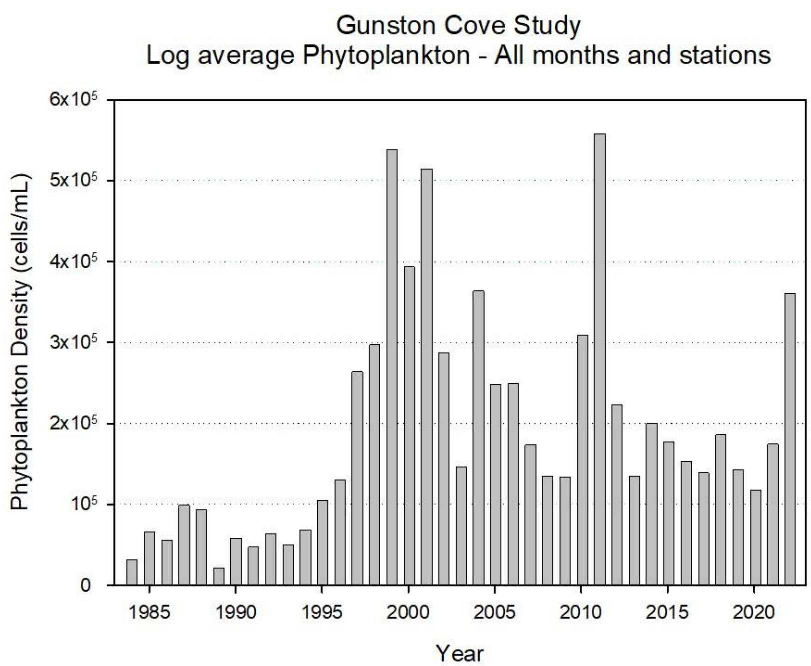
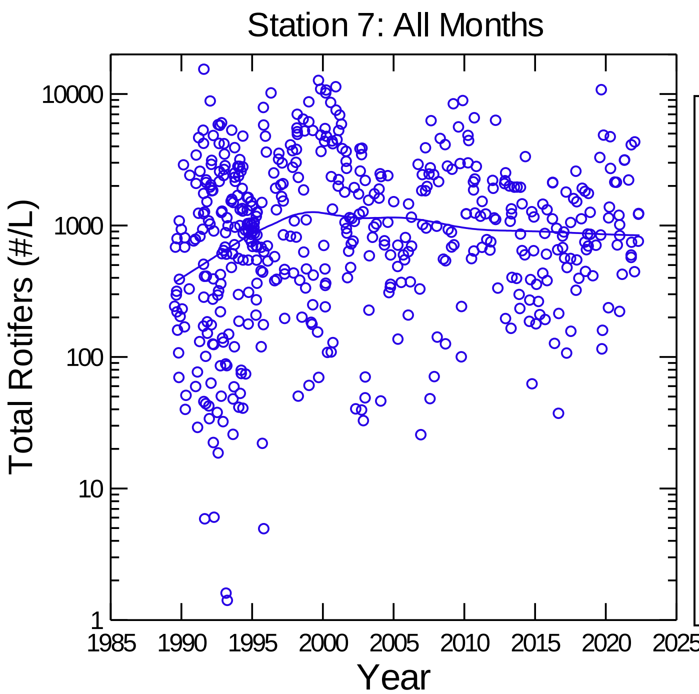


Figure 124. Interannual Trend in Average Phytoplankton Density.

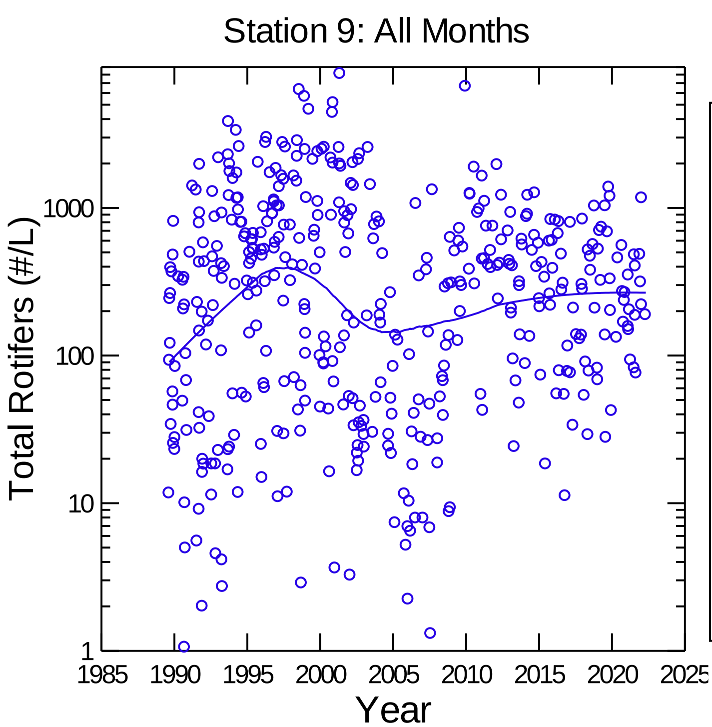
By looking at individual years (Figure 124), we see that phytoplankton densities in 2022 were substantially higher in the last decade, but were lower than the peak years of the past.

D. Zooplankton Trends: 1990-2022



In the Cove total rotifers have been stable after an initial decade (1990-2000) of steady increase (Figure 125). The LOWESS fit line indicated about 800/L in 2022, 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 19), but it is becoming more tenuous.

Figure 125. Long term trend in Total Rotifers. Station 7. Gunston Cove.



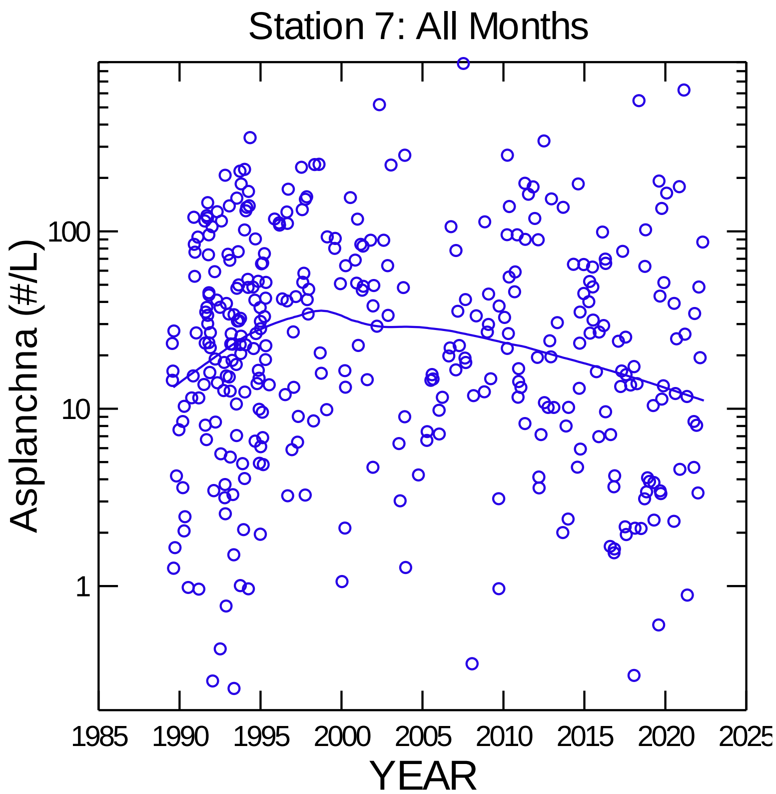
In the Potomac mainstem, rotifers exhibited an initial increase from 1990 to 1998, followed by a decline from 1999 to 2005 and more recently another increase (Figure 126). Trend line values in 1990 were about 80/L and as of 2022 are about 300/L approaching 1998 values. However, when the entire 1990-2018 period was considered, total rotifers did not exhibit a significant linear trend in the river (Table 19).

Figure 126. Long term trend in Total Rotifers. Station 9. River mainstem.

Table 19
Correlation and Linear Regression Coefficients
Zooplankton Parameters vs. Year for 1990-2022
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)	0.066 (359)	---	NS	0.089 (222)	---	NS
Brachionus (m)	0.101 (490)	0.009	0.025	0.085 (413)	---	NS
Conochilidae (m)	0.041 (424)	---	NS	0.145 (342)	-0.012	0.007
Filinia (m)	0.116 (432)	0.010	0.016	0.177 (309)	-0.012	0.002
Keratella (m)	0.243 (499)	0.018	<0.001	0.093 (424)	0.008	0.056
Polyarthra (m)	0.082 (472)	---	NS	0.009 (394)	---	NS
Total Rotifers (m)	0.125 (518)	0.008	0.004	0.039 (438)	---	NS
Bosmina (m)	0.098 (310)	---	NS	0.131 (331)	-0.010	0.012
Diaphanosoma (M)	0.267 (415)	-0.035	<0.001	0.252 (319)	-0.028	<0.001
Daphnia (M)	0.185 (323)	-0.020	0.001	0.117 (219)	---	NS
Leptodora (M)	0.327 (252)	-0.033	<0.001	0.346 (186)	-0.032	<0.001
Copepod nauplii (m)	0.380 (497)	0.022	<0.001	0.166 (434)	0.012	0.001
Calanoid copepods (M)	0.239 (583)	-0.024	<0.001	0.085 (457)	---	NS
Cyclopoid copepods (M)	0.112 (544)	-0.011	0.009	0.087 (443)	---	NS

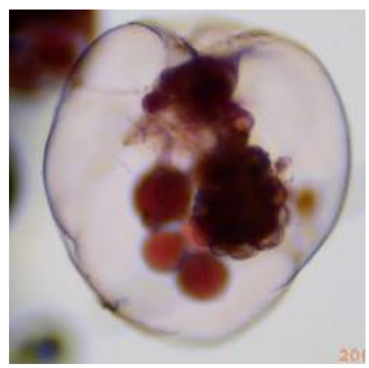
n values (# of non-zero data points) are shown in Corr. Coeff. column in parentheses. Number of total samples indicated in headings.
Significance column indicates the probability that a correlation coefficient this large could be due to chance alone. If this probability is greater than 0.05, then NS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

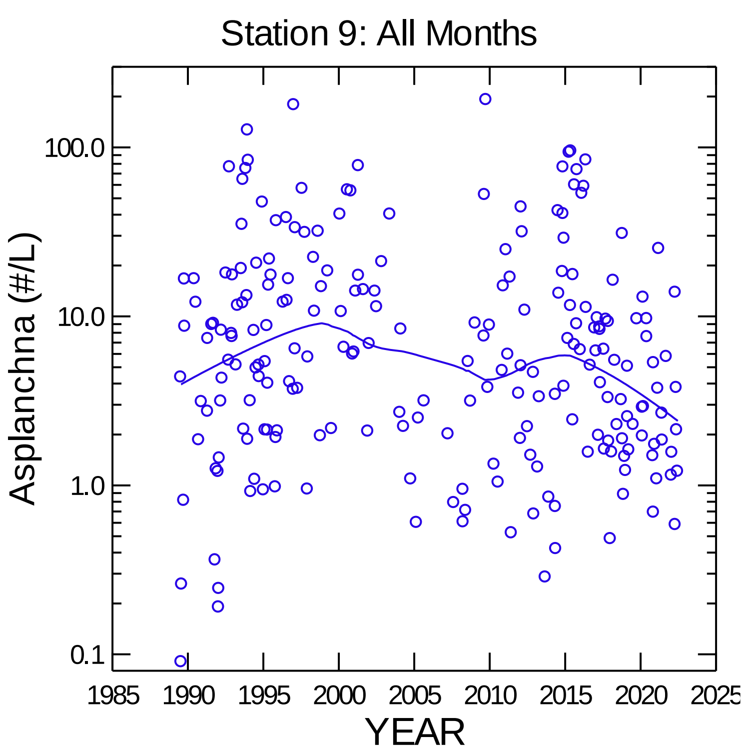


Asplanchna has shown a similar increase as total rotifers but attained much lower abundance levels (Figure 127). The LOWESS line increased in the 1990's, but has since decreased to near initial levels of about 10/L in 2022. No linear trend was found over the study period (Table 19).

Photo credit: Laura Birsa

Figure 127. Long term trend in *Asplanchna*. Station 7. Gunston Cove.





Asplanchna was found at even lower densities in the river and the trend line was at about 2.5/L in 2022 (Figure 128). No linear trend was indicated when the entire study period was considered (Table 19).

Figure 128. Long term trend in *Asplanchna*. Station 9. River mainstem.

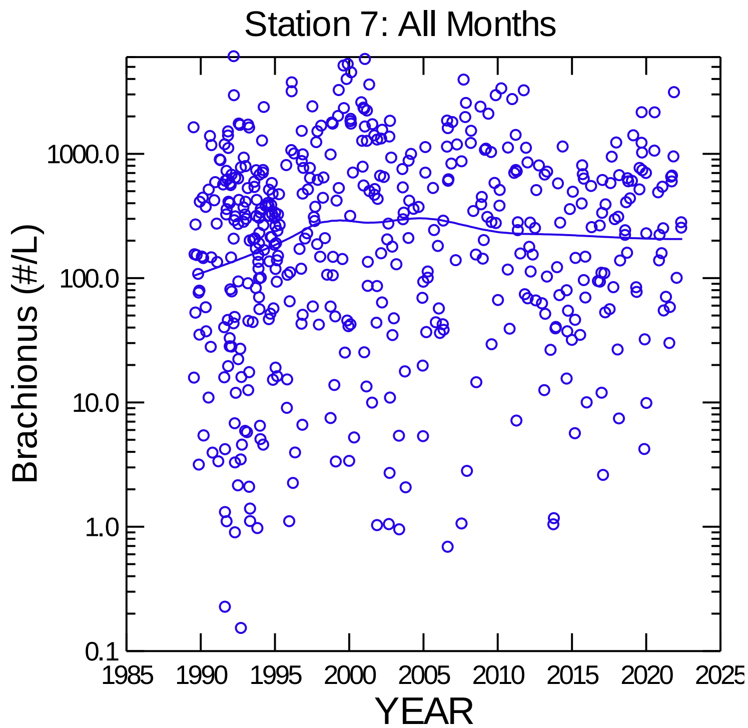


Figure 129. Long term trend in *Brachionus*. Station 7. Gunston Cove.

Brachionus is the dominant rotifer in Gunston Cove and the trends in total rotifers are generally mirrored in those in *Brachionus* (Figure 129). The LOWESS line for *Brachionus* suggested about 200/L in 2022, about twice what was found in 1990. A modest linear trend was found over the study period (Table 19).

Photo credit: Laura Birsa

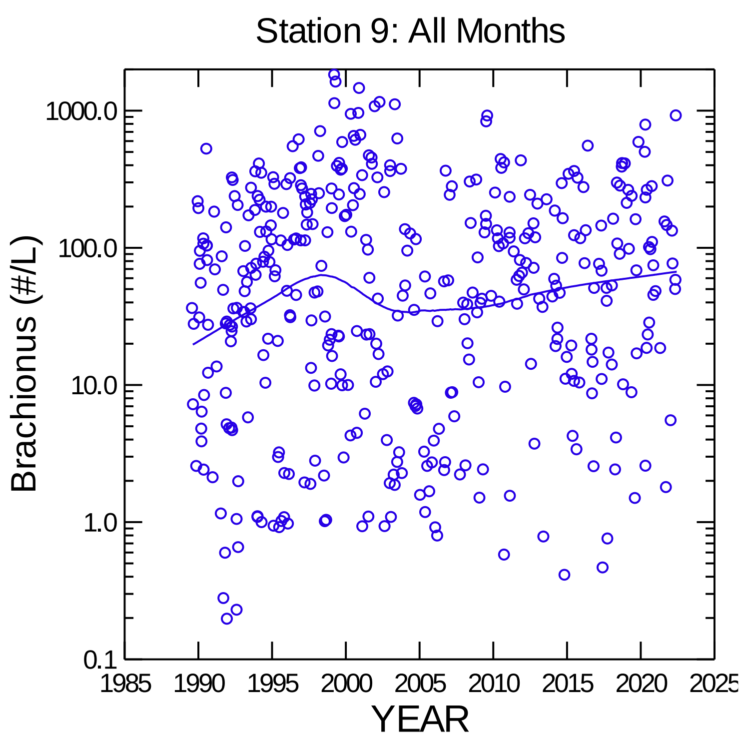
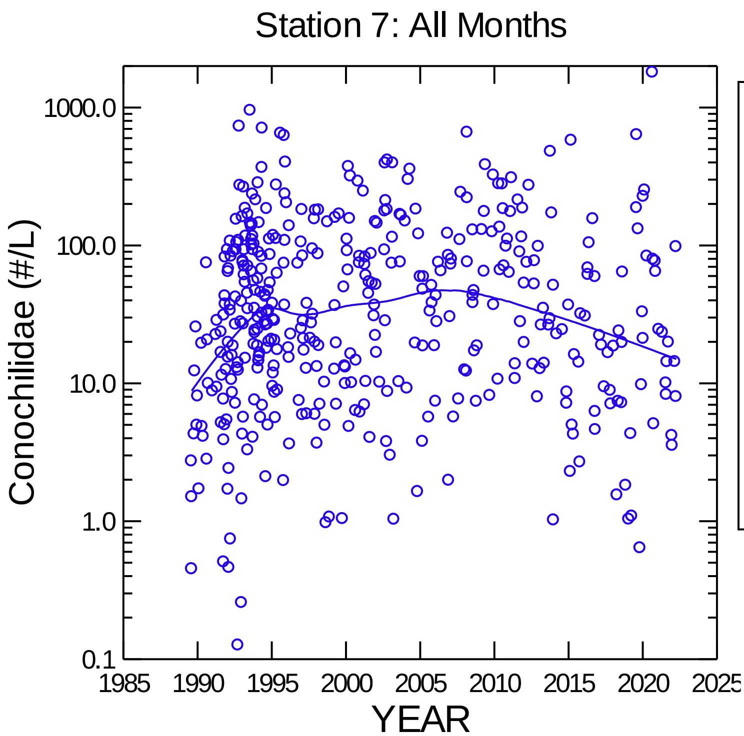


Figure 130. Long term trend in *Brachionus*. Station 9. River mainstem.

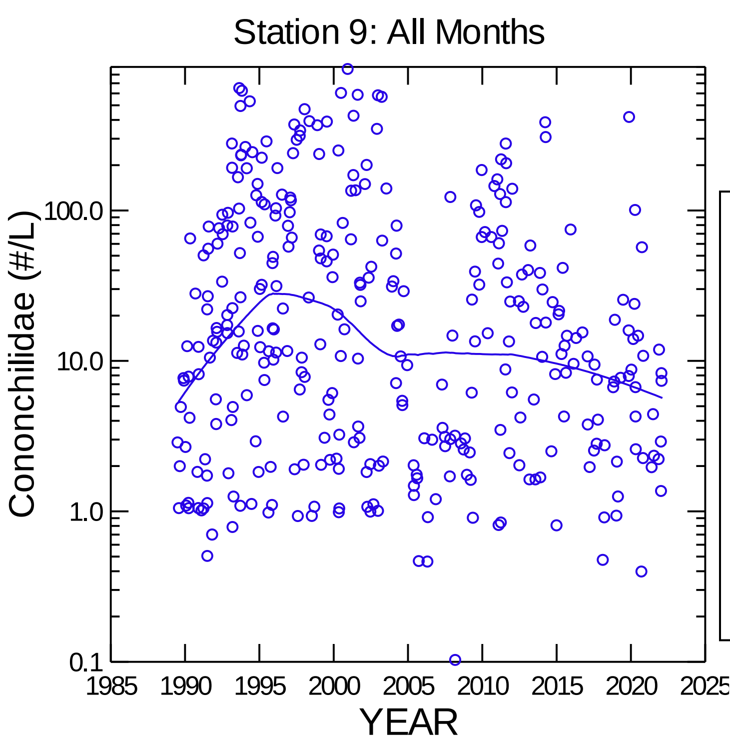
Brachionus was found at lower densities in the river. In the river the LOWESS line for *Brachionus* increased through 2000, but dropped markedly from 2000-2005. Since 2005 a steady increase has been noted with the trend line reaching about 70/L in 2022 (Figure 130). No linear trend was indicated when the entire study was considered (Table 19).



Conochilidae increased strongly from 1990-1995 and since then has leveled off and recently shows a slight decline. In 2022 the LOWESS trend line stood at about 15/L (Figure 131). This was well above levels of about 9/L in 1990. Over the entire period of record, there was not a significant linear increase (Table 19).

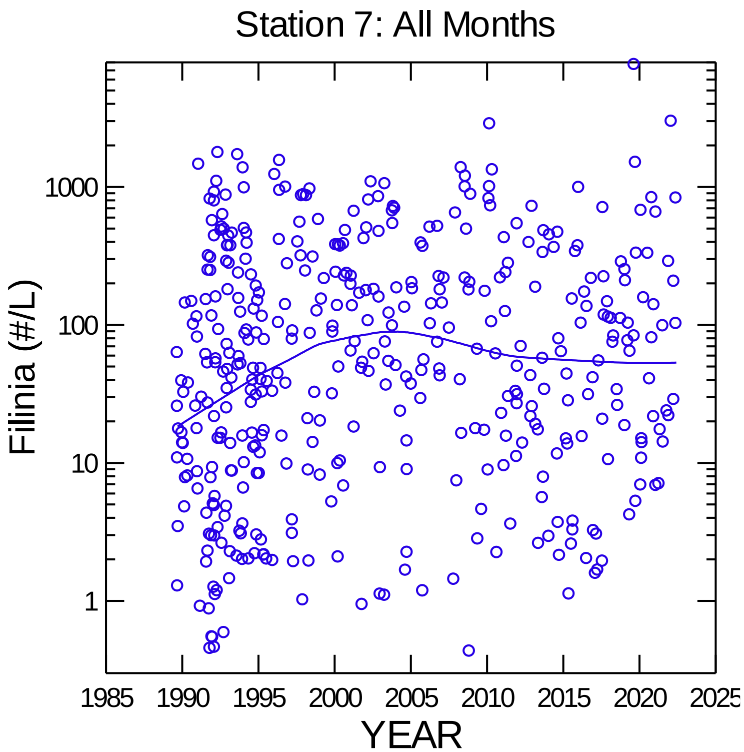
Photo credit: Laura Birsa

Figure 131. 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 132). This was followed by a period of decline and recently a constant value. The trend line has gone from 3/L in 1990 to 30/L in 1995 to about 5/L in 2022. When the entire period of record was examined, no linear trend was found (Table 19).

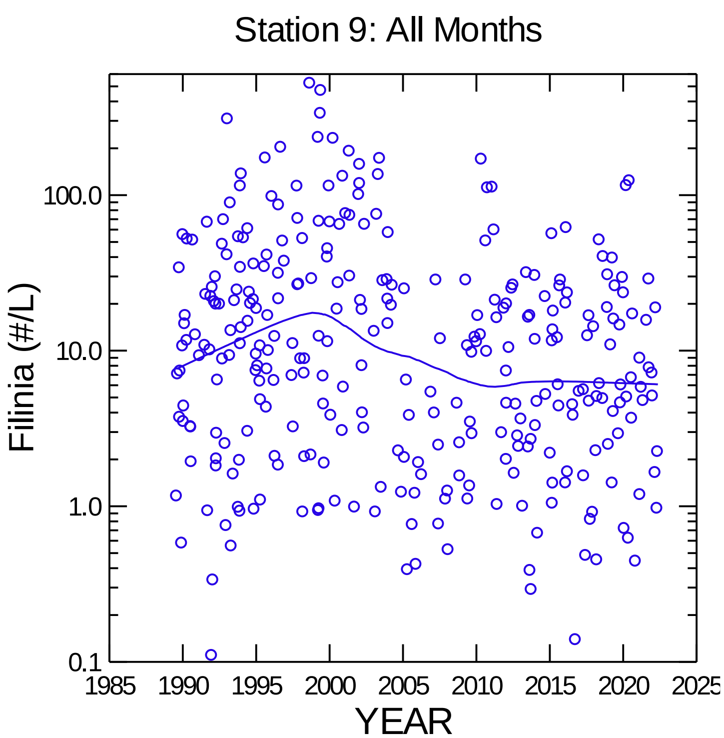
Figure 132. Long term trend in Conochilidae. Station 9. River mainstem.



In the cove *Filinia* exhibited a steady increase from 1990 through 2000 rising from about 20/L to nearly 100/L (Figure 133). It has shown a gradual decline in recent years to about 50/L in 2021. When the entire period of record was considered, there is evidence for a linear increase in the cove and in fact one very high reading 7000/L was observed in 2020 (Table 19).

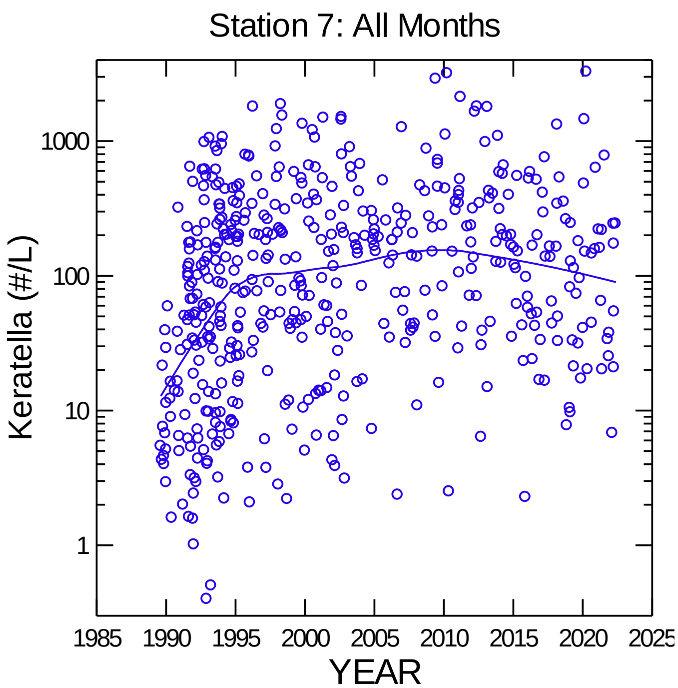
Photo credit: Laura Birsa

Figure 133. Long term trend in *Filinia*. Station 7. Gunston Cove.



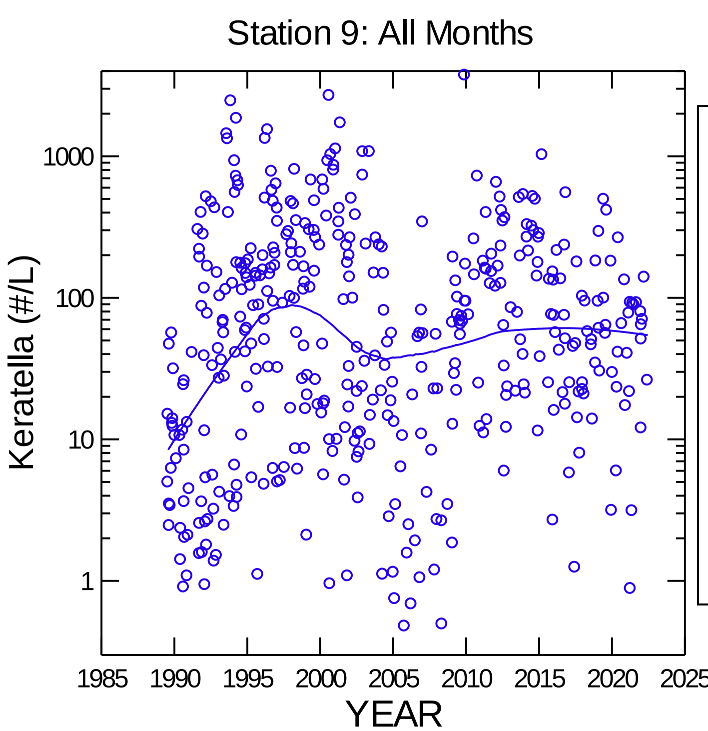
In the river *Filinia* demonstrated an increase through about 2001, declined from 2001-2010 and remained steady since. The trend line indicates about 7/L in 2022, about equal to the 7/L in 1990, but well below the peak of 20/L in 2000 (Figure 134). When the entire period of record was examined, there was a significant negative linear trend (Table 19).

Figure 134. Long term trend in *Filinia*. Station 9. River mainstem.



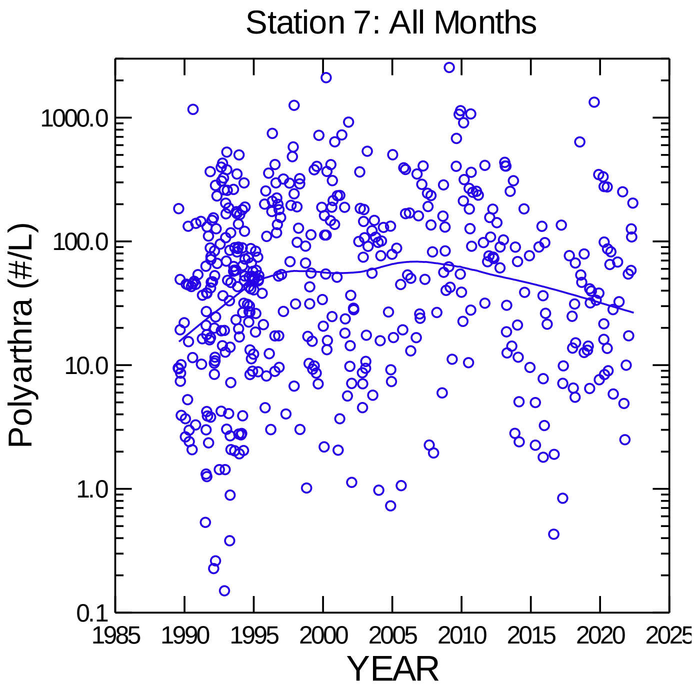
Keratella increased strongly from 1990 to 1995 and has shown a milder increase since then and most recently a slight decline with the trend line approaching 100/L in 2022 (Figure 135). When the entire period of record was examined, there was a significant linear increase (Table 19).

Figure 135. Long term trend in *Keratella*. Station 7. Gunston Cove.



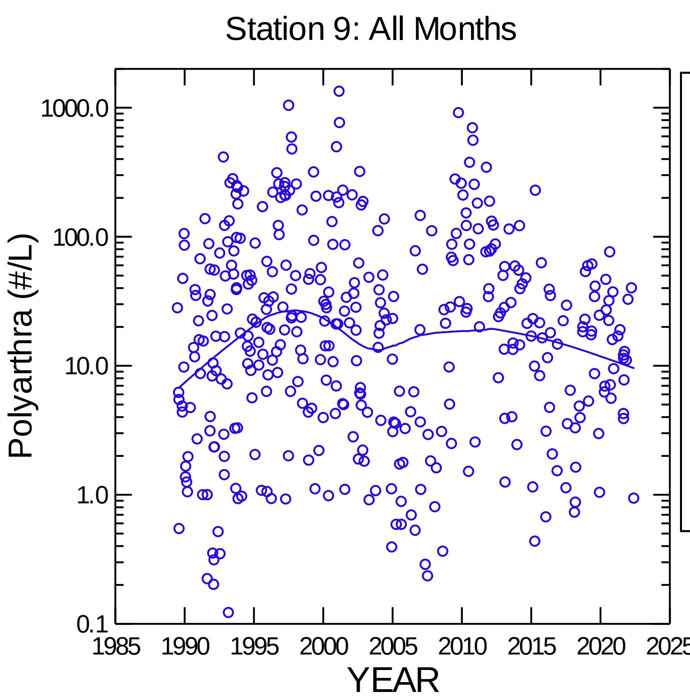
In the river *Keratella* increased from less than 10/L in 1990 to peak values of about 100/L in the mid to late 1990's (Figure 136). The trend line then declined to about 25/L, but since 2005 it has increased reaching about 60/L in 2022. Linear regression showed slight evidence of a linear increase when the entire study period was considered (Table 19).

Figure 136. Long term trend in *Keratella*. Station 9. River mainstem.



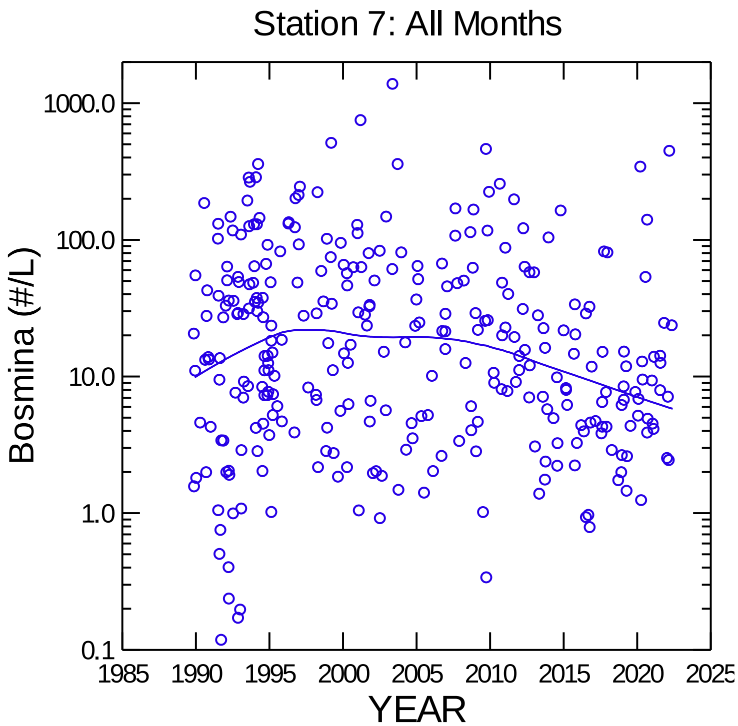
The trend line for *Polyarthra* in the cove increased steadily from 1990 to about 2000 rising from 15/L to about 60/L (Figure 137). Since 2000 densities have increased more slowly and now are dropping again reaching 30/L by 2022. Regression analysis did not reveal any significant trend over time when the entire period of record was examined (Table 19).

Figure 137. 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 2022 the trend line approached 10/L (Figure 138). Linear regression analysis failed to show a significant trend over the period of record (Table 19).

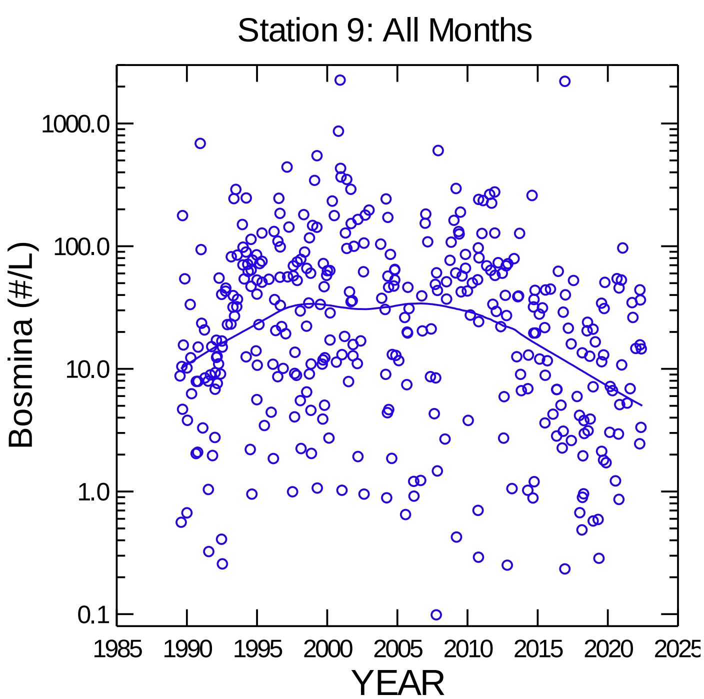
Figure 138. Long term trend in *Polyarthra*. Station 9. River mainstem.



The trend line for *Bosmina* in the cove showed an increase from 10/L in 1990 to about 20/L in 2000 (Figure 139). Since 2000 densities have declined reaching about 5/L in 2022. Linear regression did not indicate a significant trend in the cove over the entire period of record (Table 19).

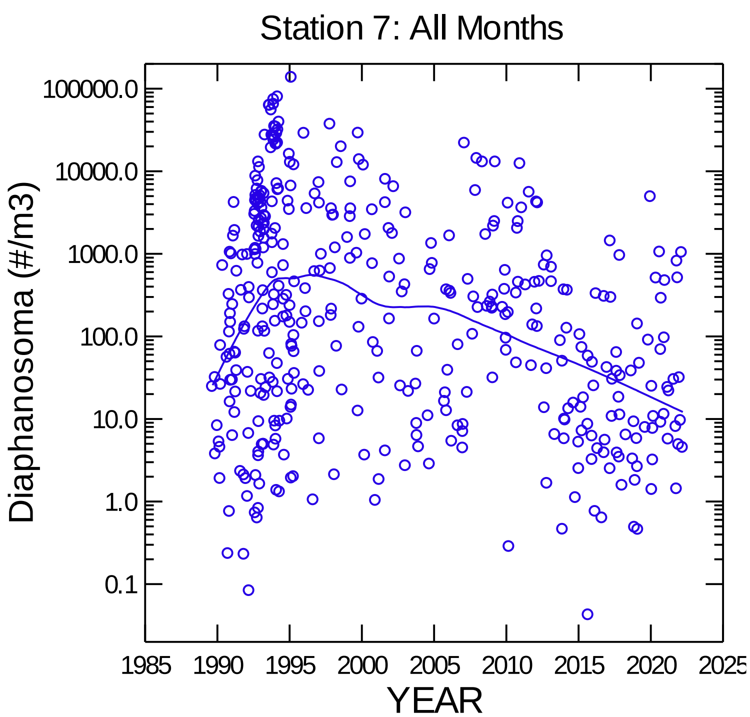
Figure 139. Long term trend in *Bosmina*. Station 7. Gunston Cove.

Photo credit: Laura Birsa



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 140). Recently, it has declined markedly to about 4/L in 2022. Regression analysis indicated a slight negative linear trend over the entire period of record (Table 19).

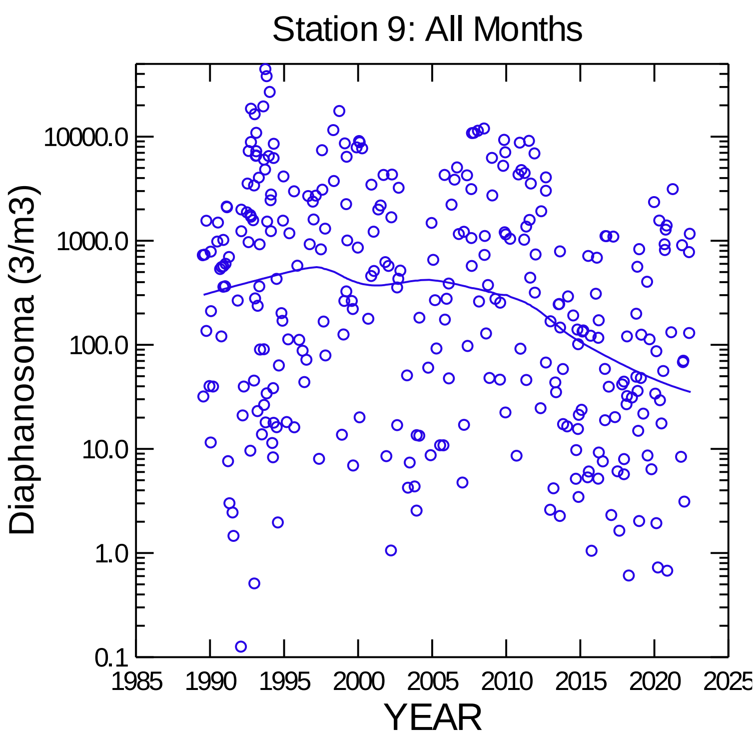
Figure 140. Long term trend in *Bosmina*. Station 9. River mainstem.



Diaphanosoma increased strongly in the early 1990s from about 20/m^3 nearly 600/m^3. It gradually declined and by 20212the trend line was nearing 10/m^3 (Figure 141). Linear regression analysis of the entire period of record indicated a significant decline (Table 19).

Photo credit: Laura Birsa

Figure 141. Long term trend in *Diaphanosoma*. Station 7. Gunston Cove.



In the river the LOWESS line suggested a generally stable pattern in *Diaphanosoma* until 2010 when a decline set in (Figure 142). The trend line value of 30/m^3 found in 2022 compared with values as high as 600/m^3 in 1999. Regression analysis indicated a significant declining trend over the period of record (Table 19).

Figure 142. Long term trend in *Diaphanosoma*. Station 9. River mainstem.

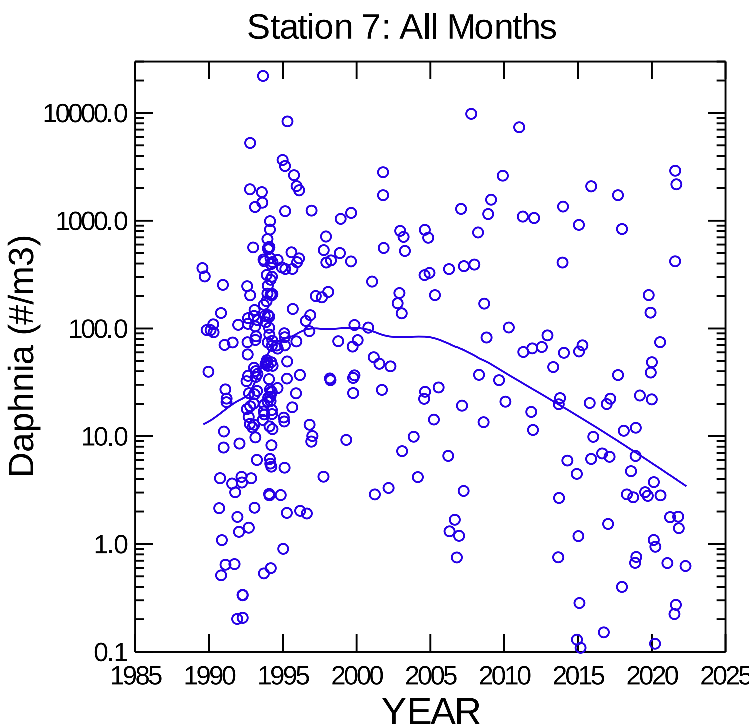


Figure 143. Long term trend in *Daphnia*. Station 7. Gunston Cove.

Daphnia in the cove has declined slowly since 1995 from about 100/m^3 to 3/m^3 in 2022 (Figure 143). Regression analysis examining the entire period of record showed a significant decline (Table 19).

Photo credit: Laura Birsa

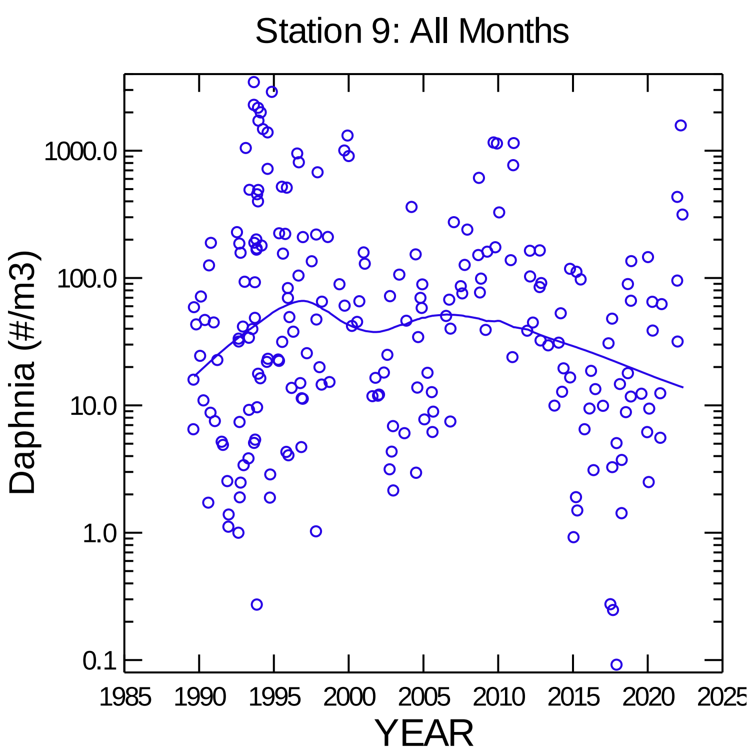
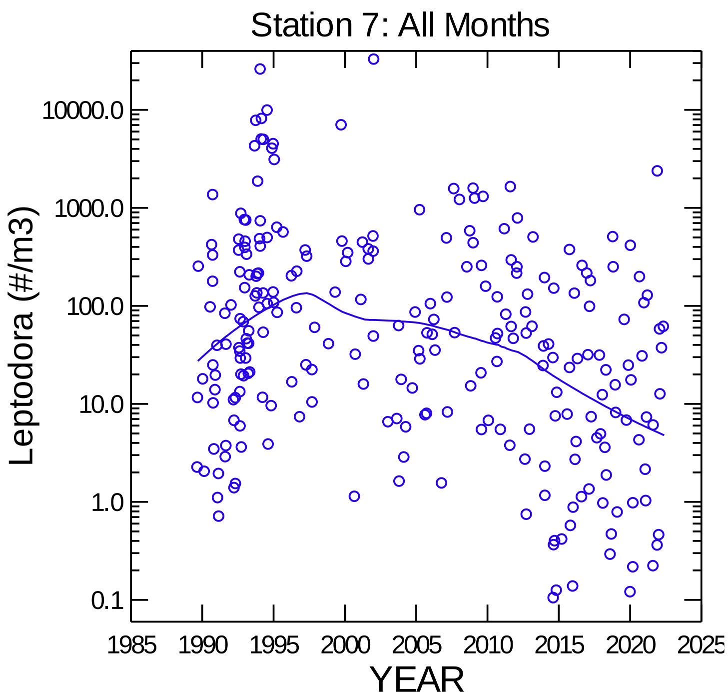


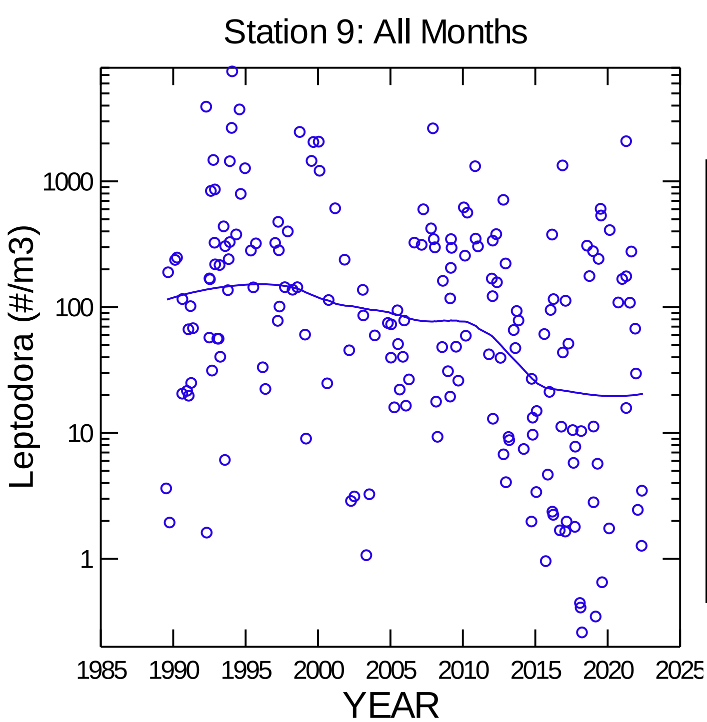
Figure 144. Long term trend in *Daphnia*. Station 9. River mainstem.

Daphnia in the river increased early on, but has since declined slightly (Figure 144). The trend line in 2022 dropped to 15/m^3, about equal to the level observed at the beginning of the record in 1990. Regression analysis failed to show a significant trend over the study period (Table 19).



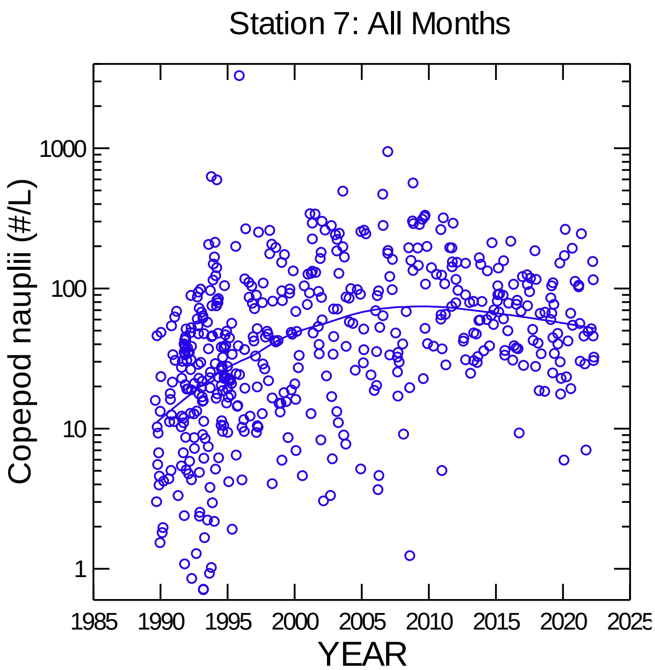
In the cove the trend line for *Leptodora*, the large predaceous cladoceran, has gradually decreased since 1995 and in 2022 reached about 4/m^3, down from its high of about 100/m^3 in 1994 (Figure 145). There was evidence for a significant negative linear trend in *Leptodora* over the entire study period (Table 19).

Figure 145. 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 20/m^3 for 2022 (Figure 146). These values are well below the peak of 200/m^3 in 1994. Linear regression analysis detected a significant negative linear trend when the whole study period was considered (Table 19).

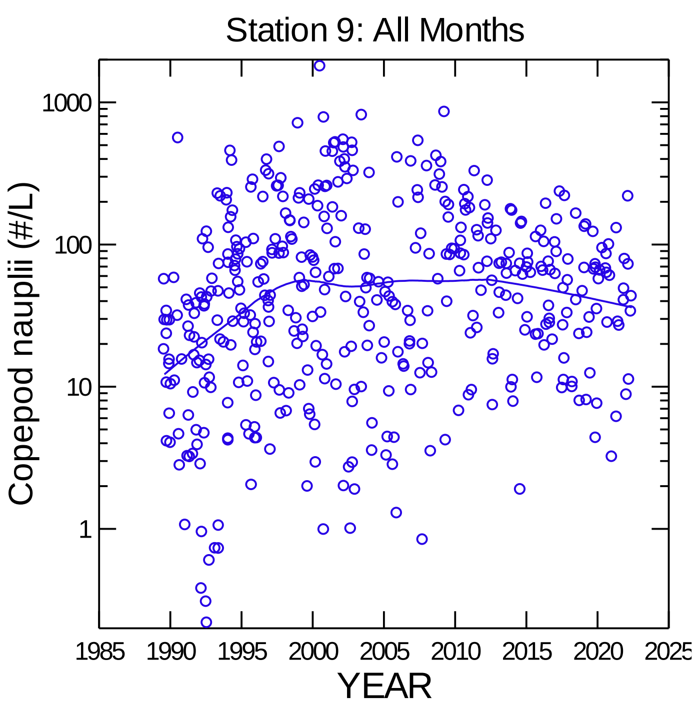
Figure 146. Long term trend in *Leptodora*. Station 9. River mainstem.



Copepod nauplii, the immature stages of copepods, have shown a positive trend since inception, but they are now leveling at about 70/L as of 2022 (Figure 147). These values are well above the initial values of about 10/L in 1990. A strong linear increase was observed over the study period (Table 19).

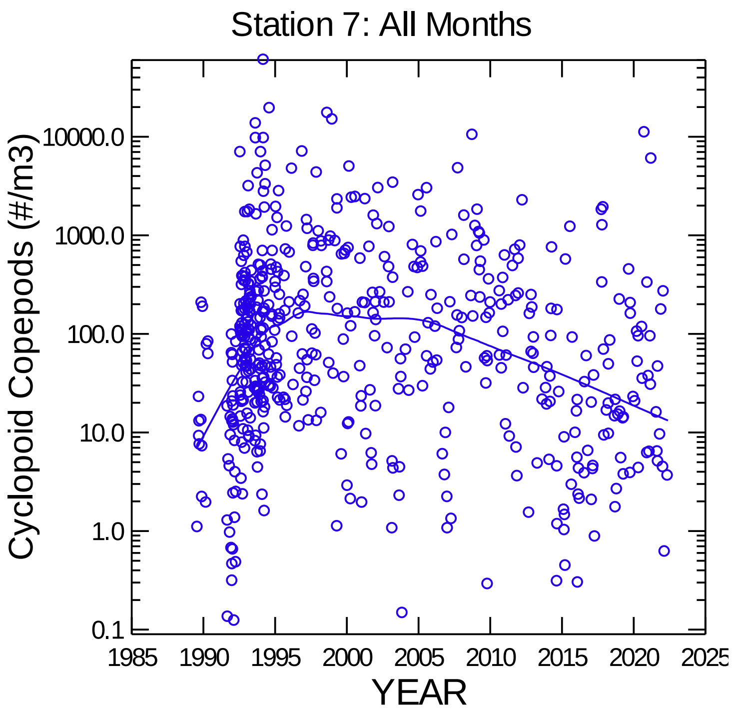
Photo credit: Laura Birsa

Figure 147. 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 148). The 2022 LOWESS trend line value was about 35/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 19).

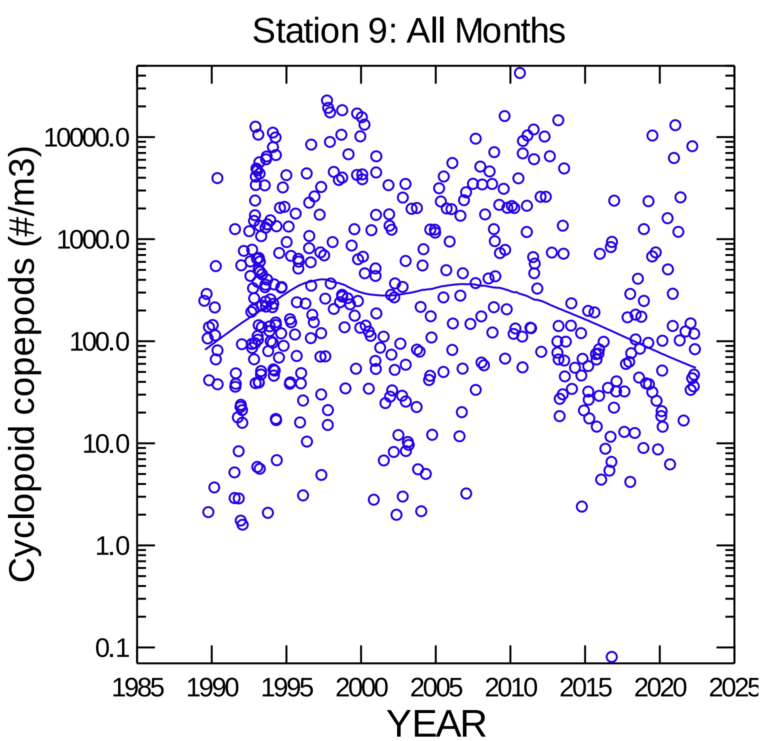
Figure 148. Long term trend in Copepod Nauplii. Station 9. River mainstem.



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 2020 (Figure 149). Cyclopoid copepods exhibited a significant negative linear trend in the cove over the study period (Table 19).

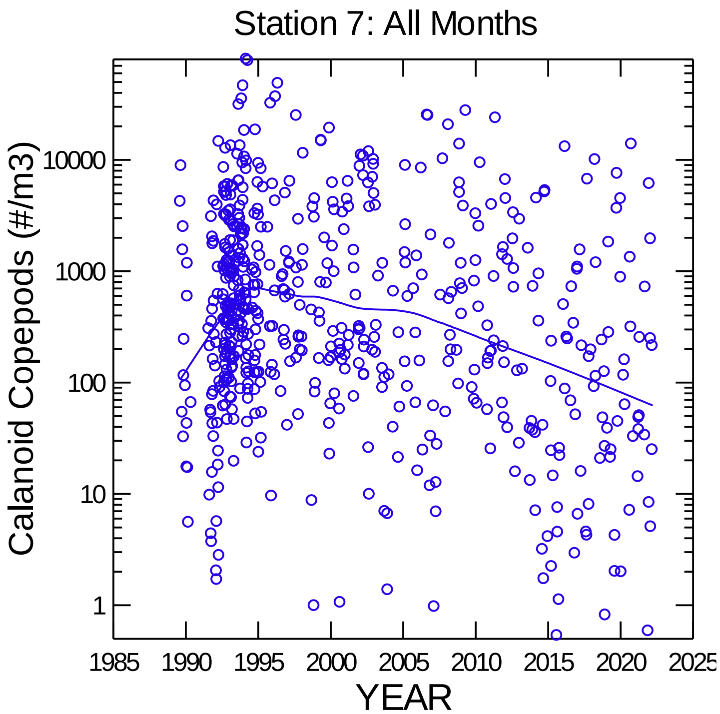
Photo credit: Laura Birsa

Figure 149. Long term trend in Cyclopoid Copepods. Station 7. Gunston Cove



Cyclopoid copepods have shown several cycles over the period in the river (Figure 150). The trend line has varied from 90/m^3 to about 400/m^3. In 2022 cyclopoids were at a low point of about 60/m^3 according to the trend line. No linear increase was found when the entire study period was considered (Table 19).

Figure 150. Long term trend in Cyclopoid Copepods. Station 9. River mainstem



Calanoid copepods (Figure 151) in the cove increased greatly in the early 1990's to near 1000/m^3 and then have gradually declined to about 60/m^3 in 2022. A significant negative trend was revealed by regression analysis (Table 19).

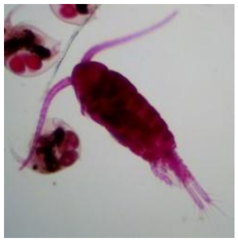
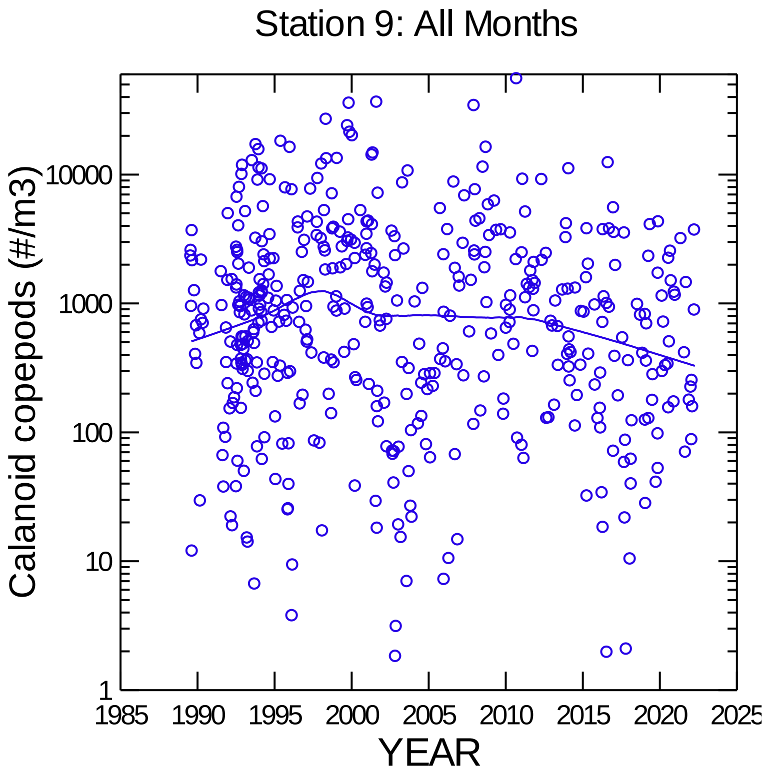


Photo credit: Laura Birsa

Figure 151. Long term trend in Calanoid Copepods. Station 7. Gunston Cove



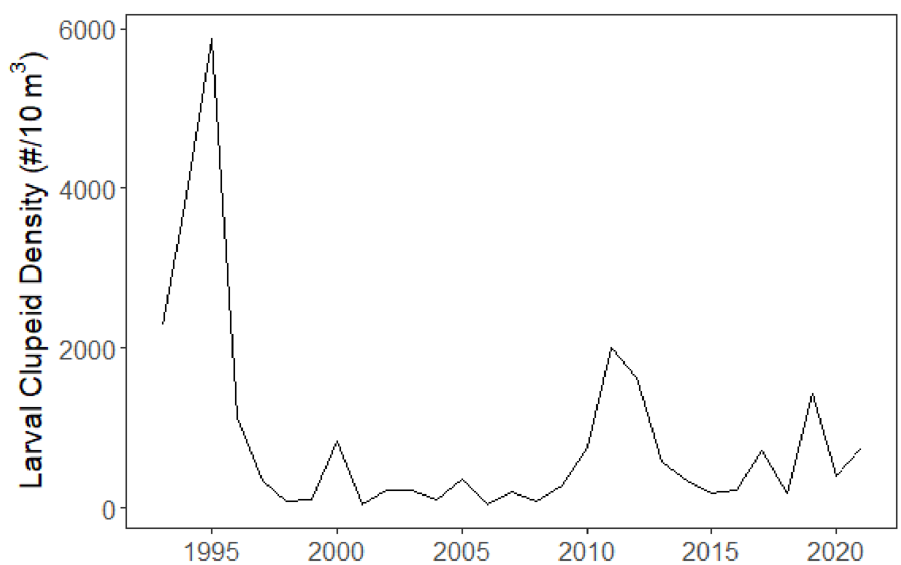
In the river calanoid copepods have varied a lot over the years, but the trend line has changed only gradually and was at 300/m^3 in 2022 (Figure 153). There was not a statistically significant linear trend (Table 16).

Figure 152. Long term trend in Calanoid Copepods. Station 9. River mainstem

E. Ichthyoplankton Trends: 1993-2022

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 (Figures 140, 142, 144, 146). 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 140; Table 17). Especially 2010-2012 showed very high density of these larvae, while numbers decreased again from 2013-2016. Although there was a small increase in 2017 and a larger increase in 2019, our 2021 and 2022 samples were almost equivalent and similar to 2017 levels. It is possible that this is natural variation, and that these populations rely on a few highly successful year classes. However, from 2017 – 2022 the numbers are higher than the early 2000. A moratorium on river herring since 2012 may be allowing the numbers to increase over time.



The trend in number of White Perch and Striped Bass larvae per 10 m^3 since 1993 is depicted in the graph in Figure 153. Two peaks are observed in 1995 and 2012 with low densities in other years.

Figure 153. Long-term trend in Clupeid Larvae (*Alosa* sp. and *Dorosoma* sp.)

Table 17. 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
2022	201	141	5	231	2	8
2021	510	84	1	88	0	20
2020	176	155	1	95	0	44
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 154, 156, 158, and 160). Clupeid larval density shows a distinct peak mid-May (Figure 154). 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. *Morone* sp., which are mostly White Perch, have high larval abundances early in the season and then taper off (Figure 156). Silversides have a small peak in late May/early June, with low densities continuing to be present throughout the season (Figure 158). The earliest peak is from Yellow Perch (Figure 160), which may even be at its highest before our sampling starts.

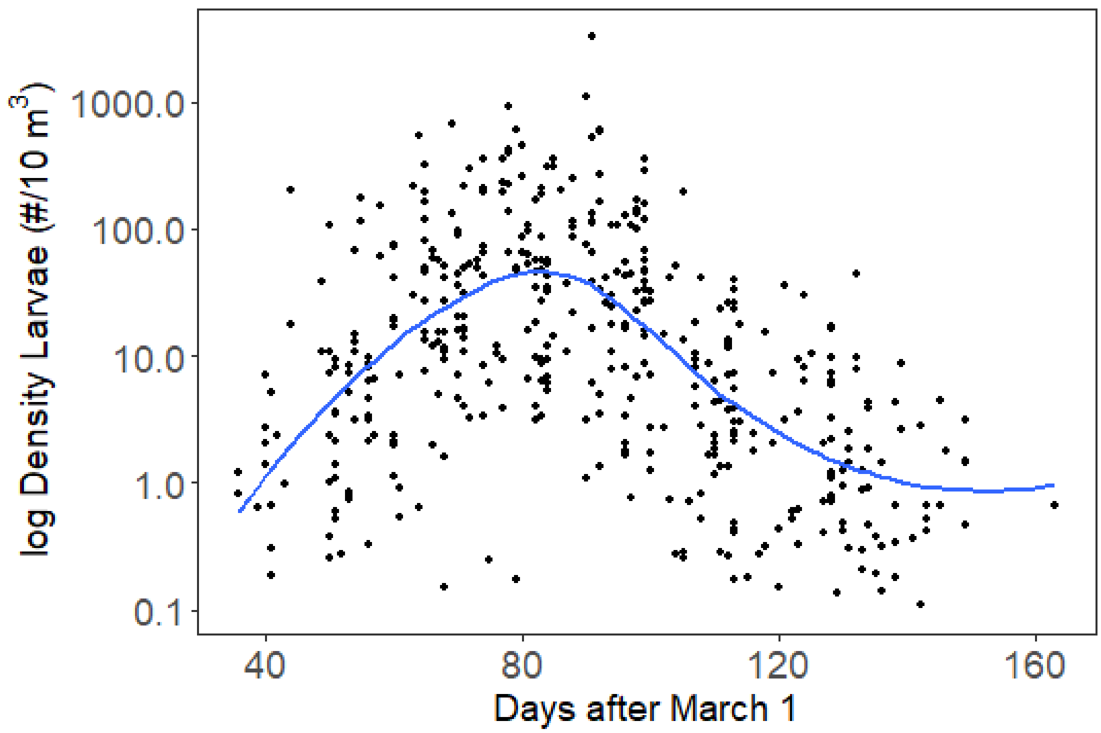
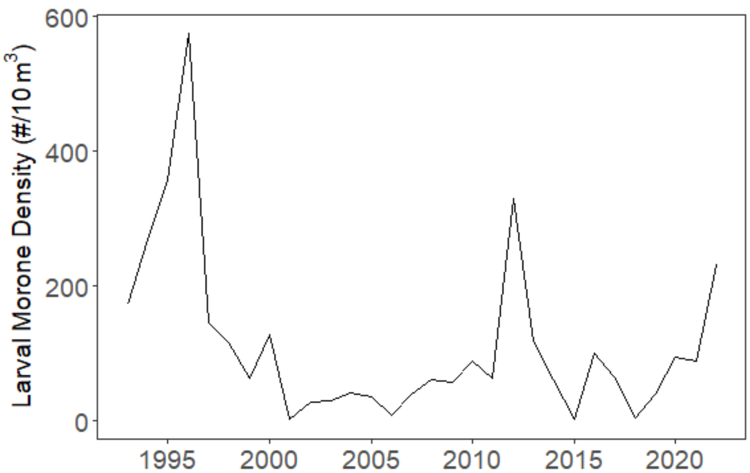


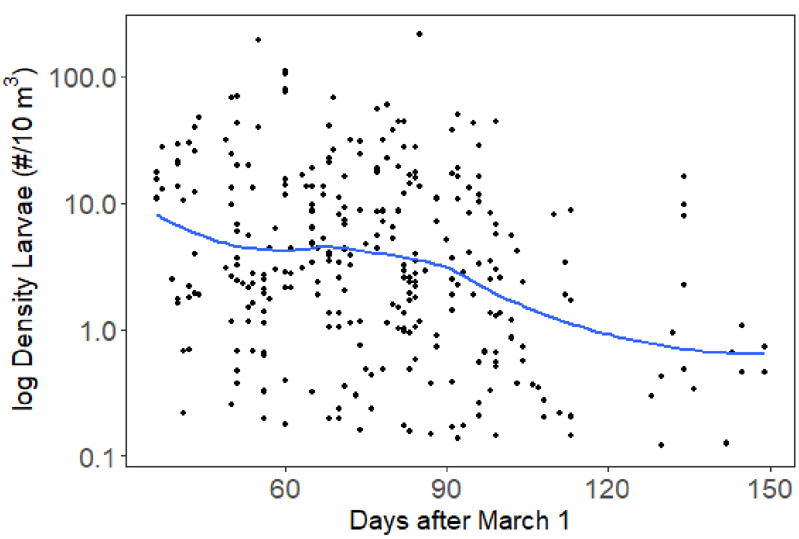
Figure 154. Seasonal pattern in Clupeid larvae (*Alosa sp.* and *Dorosoma sp.*; abundance 10 m^{-3}) from 1993 - 2022 The x-axis represents the number of days after March 1.

The long-term trend in annual average density of *Morone* larvae shows a high similarity with that of Clupeid larvae, but a substantial increase in 2022 abundance (Figure 155). The highest larvae abundance was seen in 1995. Followed by 2012, and now 2022. In recent years juvenile abundance has been increasing, which may be leading to higher numbers of spawning adults and larvae. Looking at the seasonal pattern (Figure 156), 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 155. Two peaks are observed in 1995 and 2012 with low densities in other years.

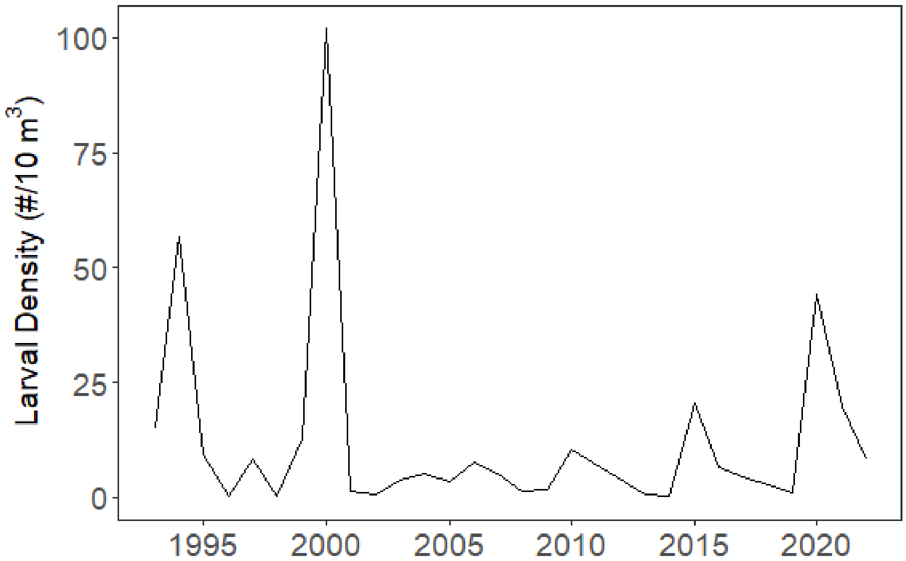
Figure 155. Long term trend in *Morone sp.* larvae (abundance 10 m^{-3}).



The seasonal density of *Morone* sp. larvae per 10 m^3 is shown in Figure 156. Highest densities are at the start of the sampling season.

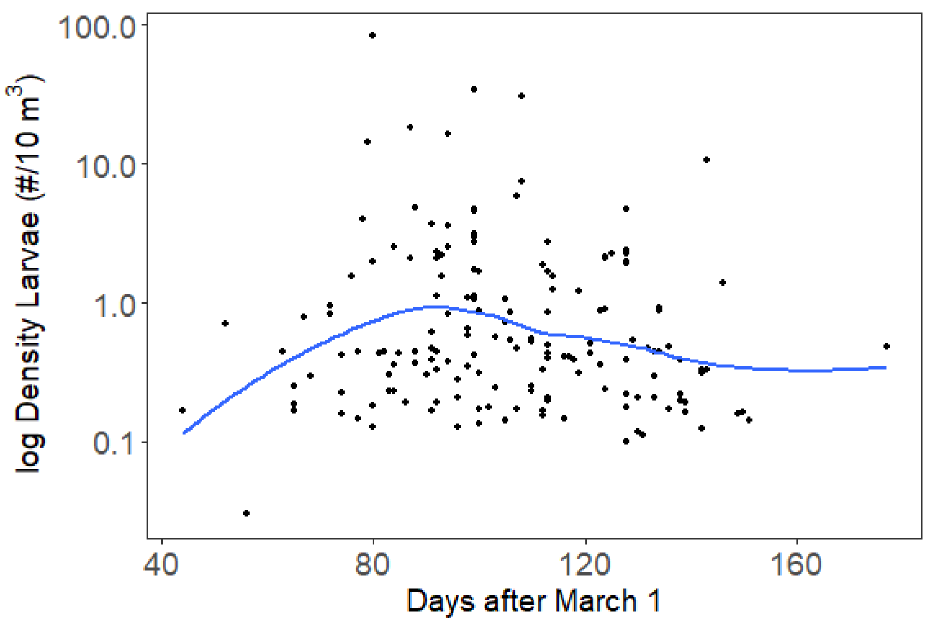
Figure 156. Seasonal pattern in *Morone sp.* larvae (abundance 10 m^{-3}) from 1993-2022. X-axis represents days after March 1st.

The long-term in annual average density of Inland Silverside larvae also shows the highest peaks early in the timeseries, with highest peaks occurring in 1994 and 2000. However, after some small peaks in 2006, 2010, and 2015, 2020 showed the third highest peak in the period of record. However, after this 2020 peak numbers have continued to decrease.



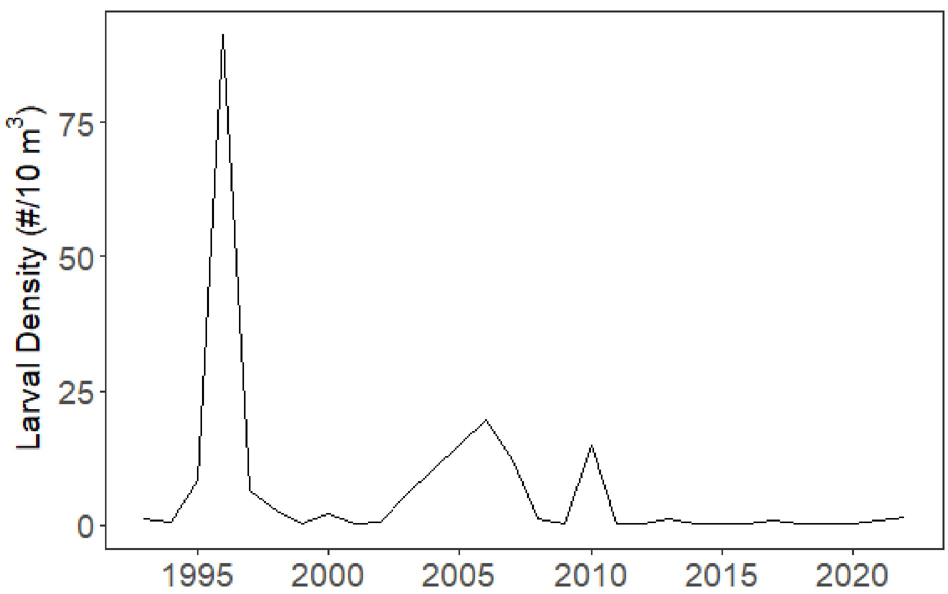
The long-term trend in density of Inland Silverside is presented in Figure 157. After high peaks in 1994 and 2000, densities have been moderate to low with some small peaks in 2006, 2010, and 2015. 2020 adds the third highest peak in the period of record.

Figure 157. Long-term trend in *Menidia beryllina* larvae (abundance 10 m^{-3}).



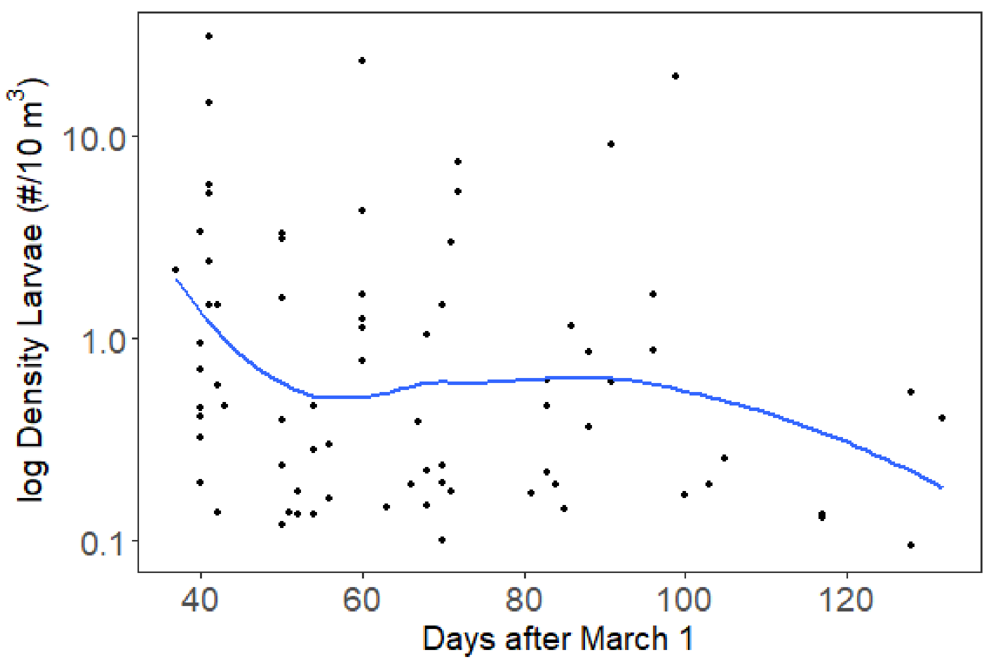
The seasonal occurrence of Inland Silverside per 10m^3 is shown in a LOWESS graph in Figure 158. The pattern shows maximum density around 90 days after March 1, or around the first week of June.

Figure 158. Seasonal pattern in *Menidia beryllina* larvae (abundance 10 m^{-3}) from 1993 - 2022. The x-axis represents the number of days after March 1.



The long-term trend in density of Yellow Perch larvae since 1993. Following unusually high densities in 1996, abundances decreased to low values, especially since 2011 (Figure 159)

Figure 159. 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 160. 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 160. Seasonal pattern in *Perca flavescens* larvae (abundance 10 m^{-3}) from 1993 - 2022. The x-axis represents the number of days after March 1.

F. Adult and Juvenile Fish Trends: 1984-2022

Trawls

Cove: Stations 7 & 10

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 18, Figure 161). 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 148). 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 149). The White Perch numbers in 2022 were lower than 2020 and greater than 2021, remaining higher than early years, continuing the trend of higher peaks and shallower troughs since 2006. (Figure 148). The high numbers of White Perch were predominantly small juveniles and all trawl stations in 2022 were dominated by White Perch.

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 relatively small part of the catch between 1991 and 2000; and moderate to large proportion of the catch from 2001 to 2022. There was a high peak in catches other than White Perch in 2004, which was primarily due to exceptionally high catches of Blueback Herring (Figure 161; Figure 162). The high peak in Blueback Herring catches in 2004 stands out in otherwise low catches (Figure 162). Generally, both herring species were found in higher abundances from 2000 – 2015, than in the decade before that. We included *Alosa* sp. (unidentified herring or shad) in Figure 162 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, followed by 2015. Unfortunately, the last few years have had low *Alosa* catches in trawls similar to pre 2000 catches.

Gizzard Shad (*Dorosoma cepedianum*) catch rates in trawls in 2022 were much higher than recent years and this is the second highest abundance observed since the high peak in 1989 (Figure 163). Smaller peaks have also occurred in 1991, 1997, 2008, and 2012, that were all an order of magnitude lower than the 1989 peak and lower than the new 2022 peak. Bay Anchovy (*Anchoa mitchilli*) catch rates in 2022 were higher than most previous years, exhibiting a peak similar to 2007. With this observation it appears the decreasing trend in the data is not holding and it will be interesting to see what 2023 holds. Although Bay Anchovy are estuarine residents, they are opportunistic spawners and are expected to exhibited both weak and strong year classes depending upon what spawning events are successful.

Table 18. Mean catch per trawl of adult and juvenile fishes at Stations 7 and 10 combined. 1984-2022.

Year	All Species	White Perch	All Alosa Sp.	Blueback Herring	Alewife	Gizzard Shad	Bay Anchovy	Spottail Shiner	Brown Bullhead	Pumpkinseed
2022	259.6	197.9	7.7	5.1	1.6	9.3	15.1	20.6	0.0	2.6
2021	158.1	107.2	11.3	4.6	4.8	0.2	1.8	15.8	0.0	2.7
2020	568.7	522.1	2.6	0.3	2.0	0.7	0.0	33.9	0.1	4.3
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	0.1	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	0.1	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	0.1	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	21.0	33.1	11.8	16.4	1.1	0.0	6.6	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	81.6	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

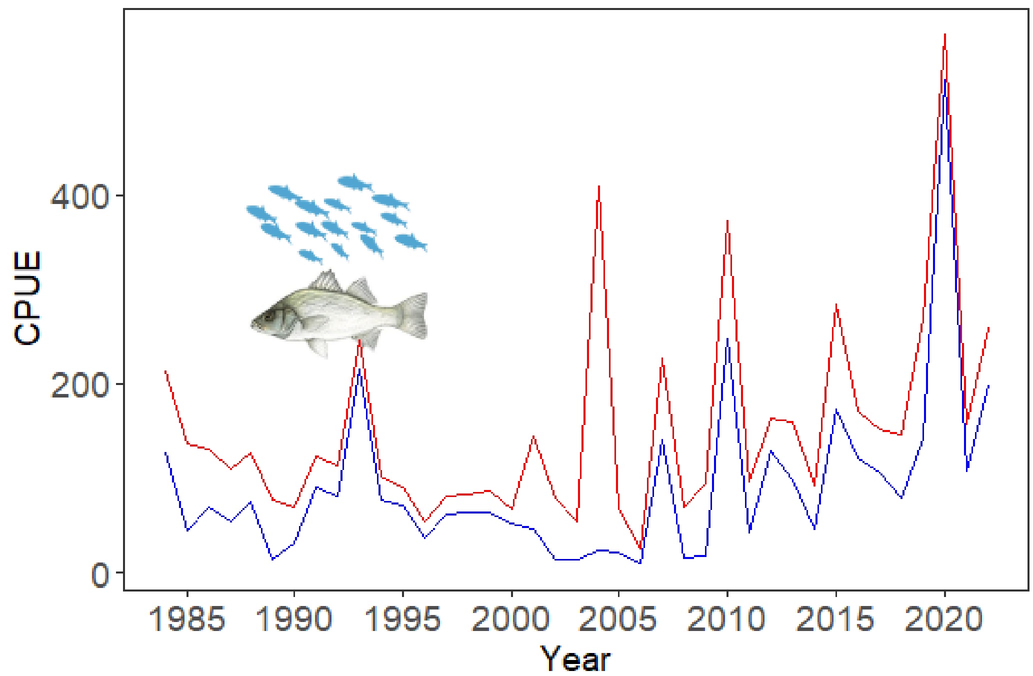


Figure 161. Trawls. Annual Averages. All Species (red) and *Morone americana* (blue). Cove Sites 7 and 10. 1984-2022.

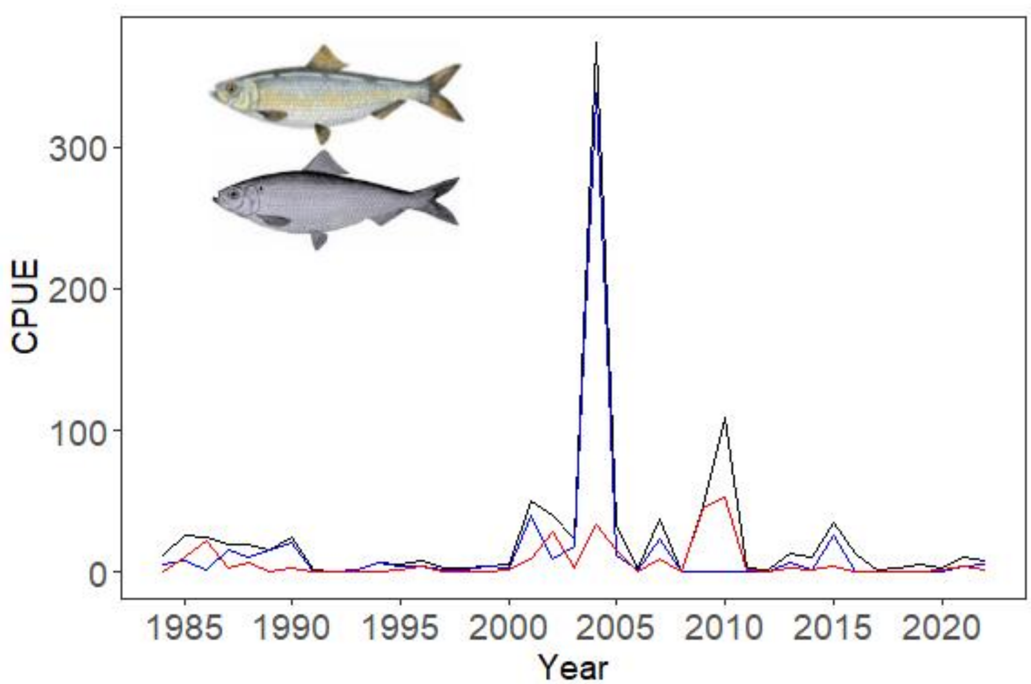


Figure 162. Trawls. Annual Averages. *Alosa aestivalis* (blue), *Alosa pseudoharengus* (red), and all combined *Alosa sp.* (black). Cove Sites 7 and 10.

Spottail Shiner (*Notropis hudsonius*) and sunfishes (*Lepomis* sp.) have been consistently collected in most trawl and seine samples (Figure 164). 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 164). 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. In 2022 the numbers were higher than 2021 and contributed to the overall increasing trend. 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.

Bullhead Catfish catches were once again low in 2022, fitting the trend of continuing decline that has proceeded continuously since the start of the survey (Figure 165). Tessellated Darter (*Etheostoma olmstedi*) numbers were similar to 2022, but still much lower than the 2018 highest observed abundance peak (Figure 166). The second highest peak in the period of record was observed in 1992. The consistent numbers in 2022 tracks well with an increasing trend since 2005 as well, potentially as a result of the SAV expansion mentioned above.

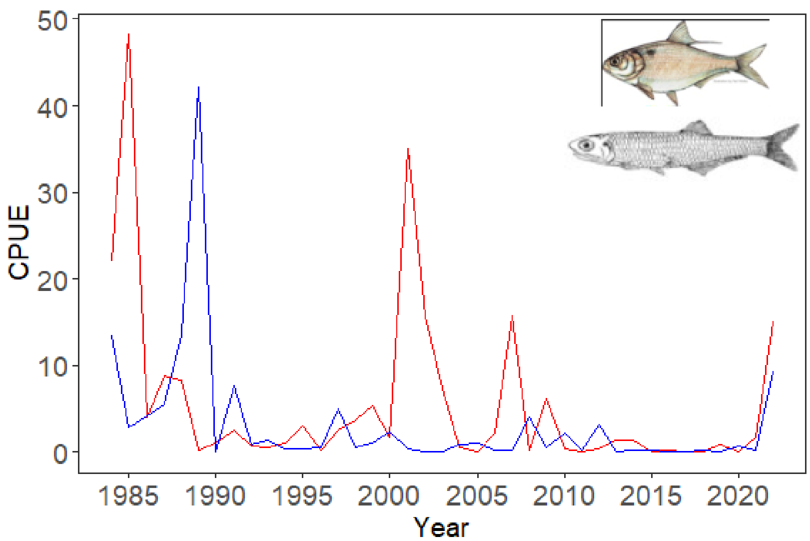


Figure 163. Trawls. Annual Averages. Cove Sites 7 and 10. *Dorosoma cepedianum* (blue) and *Anchoa mitchilli* (red).

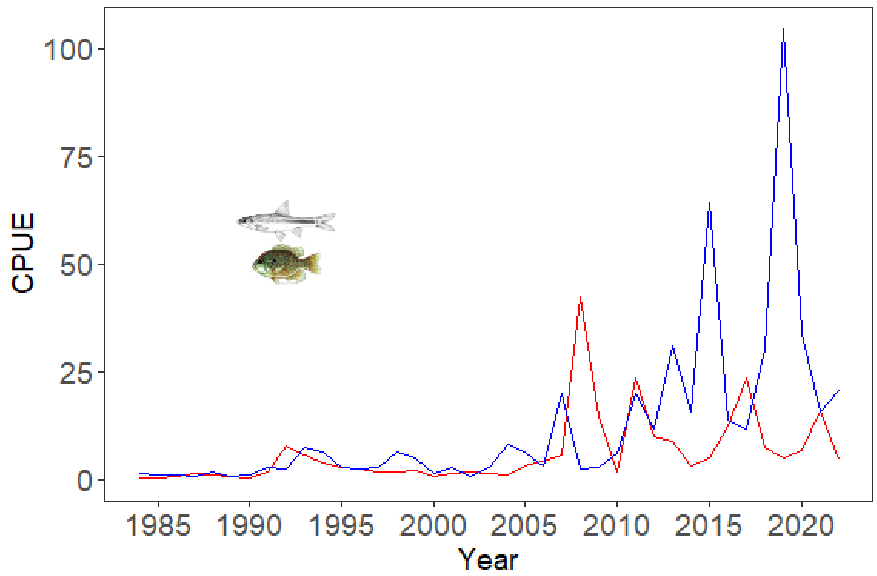


Figure 164. Trawls. Annual Averages. *Notropis hudsonius* (blue) and all *Lepomis sp.* (red). Cove Stations 7 and 10.

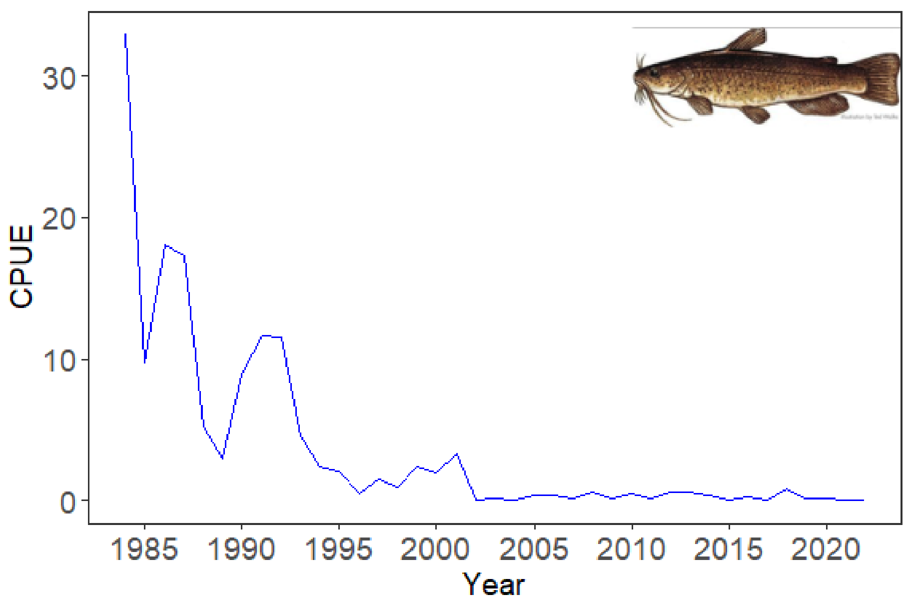


Figure 165. Annual Averages. *Ameiurus nebulosus*. Cove Stations 7 and 10.

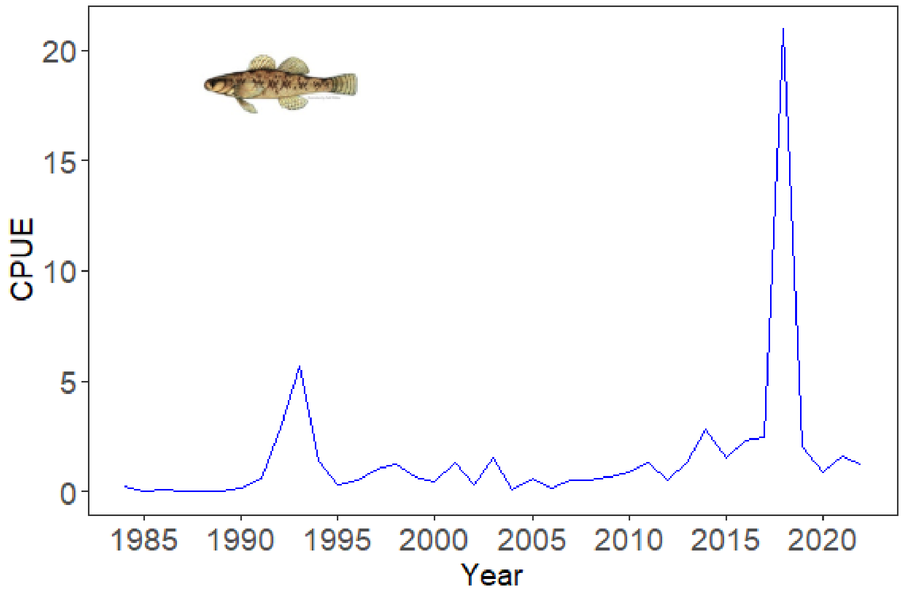


Figure 166. Trawls. Annual Averages of *Etheostoma olmstedi*. Cove stations 7 and 10.

River: Station 9

Mean total catch at station 9 (river channel) in 2022 was lower than 2021 and continued a declining trend at this station (Figure 167, Table 19). Total catch was mainly comprised of White Perch, and both total catch and White Perch abundance decreased in 2022. The high total abundance in 2019 was due to catches of Spottail Shiner and Alosines. In 2018 an increase in catch was due to an increase in Blue Catfish catch. Blue Catfish was spotted in Station 9 again in 2019, 2020, 2021, and now in 2022 with 18 individuals collected. Blue Catfish are regularly collected at station 9 and now occur at the inner cove stations. In 2022 Blue Catfish were collected at all stations demonstrating further encroachment into the cove, continuing a trend seen in 2021.

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 168). However, no Bay Anchovy or American Eel were collected at Station 9 in 2022. Spottail Shiner is found in low numbers every year at station 9, which saw an uptick in 2019, and remained relatively high in 2020, but decreased again in 2021, with 2022 numbers remaining low. American Eel has remained rare since 1994.

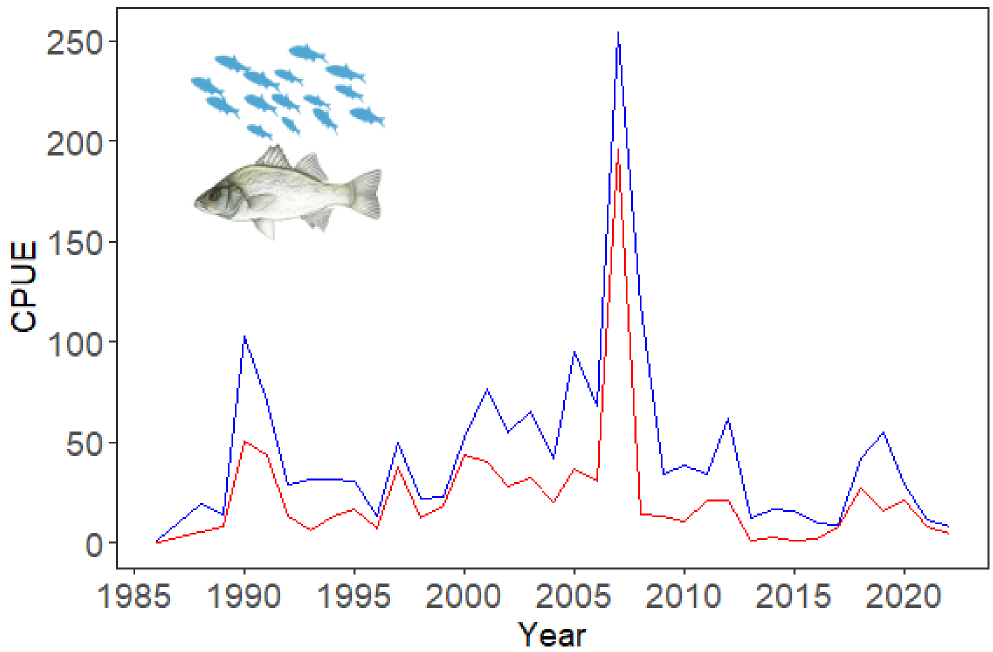


Figure 167. Trawls. Annual averages. River Station (9). Total catch (blue) and *Morone americana* (red).

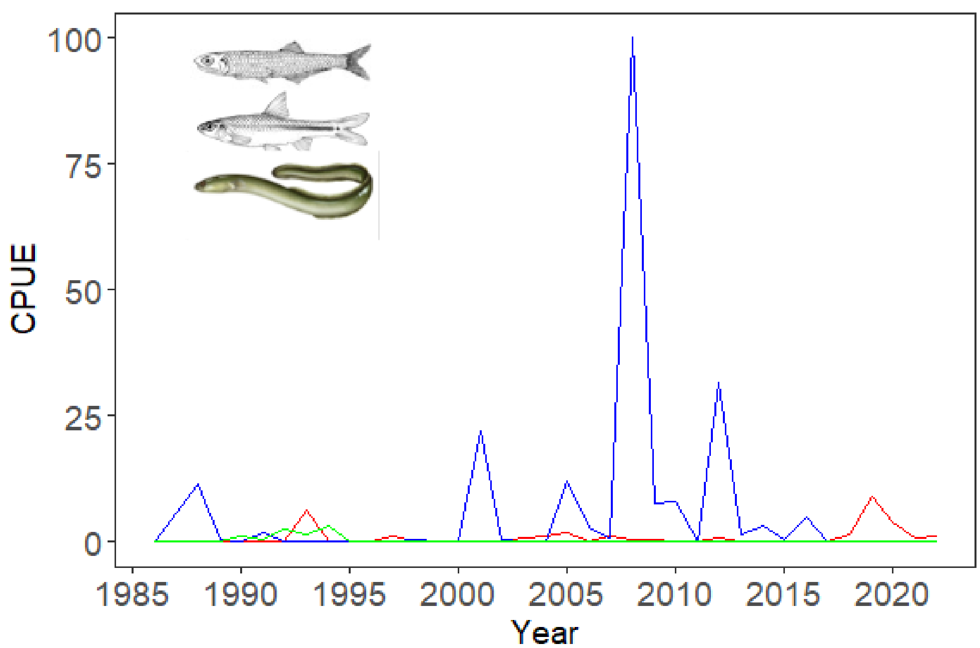


Figure 168. Trawls. Annual Averages. River Station (9). *Anchoa mitchilli* (Blue), *Notropis hudsonius* (red), and *Anguilla rostrata* (green).

Table 19. Mean catch per trawl of selected adult and juvenile fishes for all months at Station 9. 1986-2022

Year	All Species	All Alosa Sp.	Alewife	Blueback Herring	White Perch	Bay Anchovy	Spottail Shiner	Brown Bullhead	Blue Catfish	Channel Catfish	Tesselated Darter
2022	7.9	0.2	0.0	0.0	5.0	0.0	1.0	0.0	0.9	0.0	0.1
2021	11.8	0.5	0.0	0.0	8.2	0.1	0.7	0.0	2.0	0.0	0.1
2020	29.2	0.2	0.2	0.0	20.8	0.0	3.8	0.0	3.6	0.2	0.0
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	1.0	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

Catch rates for native catfish species have been variable and low at station 9 since 2007 (Figure 169), with only a small peak from Channel Catfish in 2011. No native catfishes were collected at station 9 in 2022, and only White and Brown Bullheads were collected elsewhere. However, even with these few collected individuals, native catfish declines remain. 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 169). In 2022, we collected 9 Blue Catfish at station 9, the most of any other station. 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 numbers have remained relatively consistent over the last few years, albeit higher than native catfishes, potentially indicating a new stable state with decreased native and elevated invasive catfish. Continued monitoring in the growth of this population is warranted.

Station 9 generally represents low catch rates for the demersal species Tessellated Darter and Hogchoker (Figure 170). 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 or Tessellated Darters were collected in 2020, while a low number Tessellated Darters were collected in 2021 and 2022, but Hogchokers remained absent from our catch.

The mean catch of all trawl stations combined in 2022 (175.7) was greater than 2021 (106.1), lower than 2020 (343.9, the highest year on record), and similar to the long-term mean of 103 (Table 20). While using catch per unit effort allows for between year comparisons, the low number of trawls performed in 2020 likely provided an overly high biased estimate. Our 2022 collections indicate that trawl CPUE has remained like the long-term average.

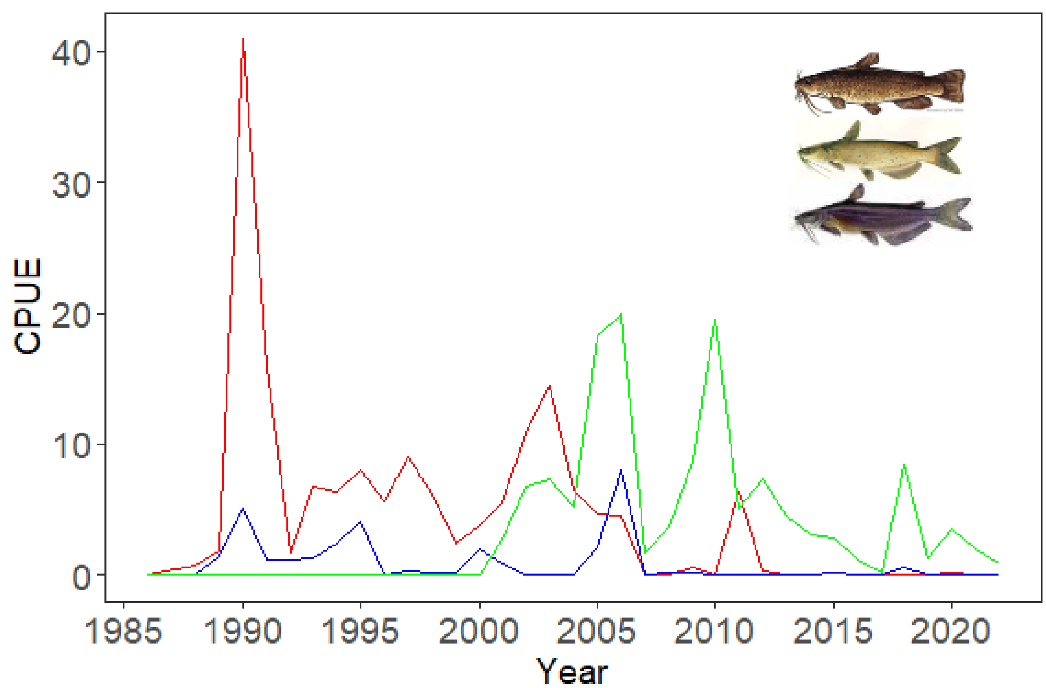


Figure 169. Trawls. Annual Averages. River Station (9). *Ameiurus nebulosus* (blue), *Ictalurus punctatus* (red), and *Ictalurus furcatus* (green).

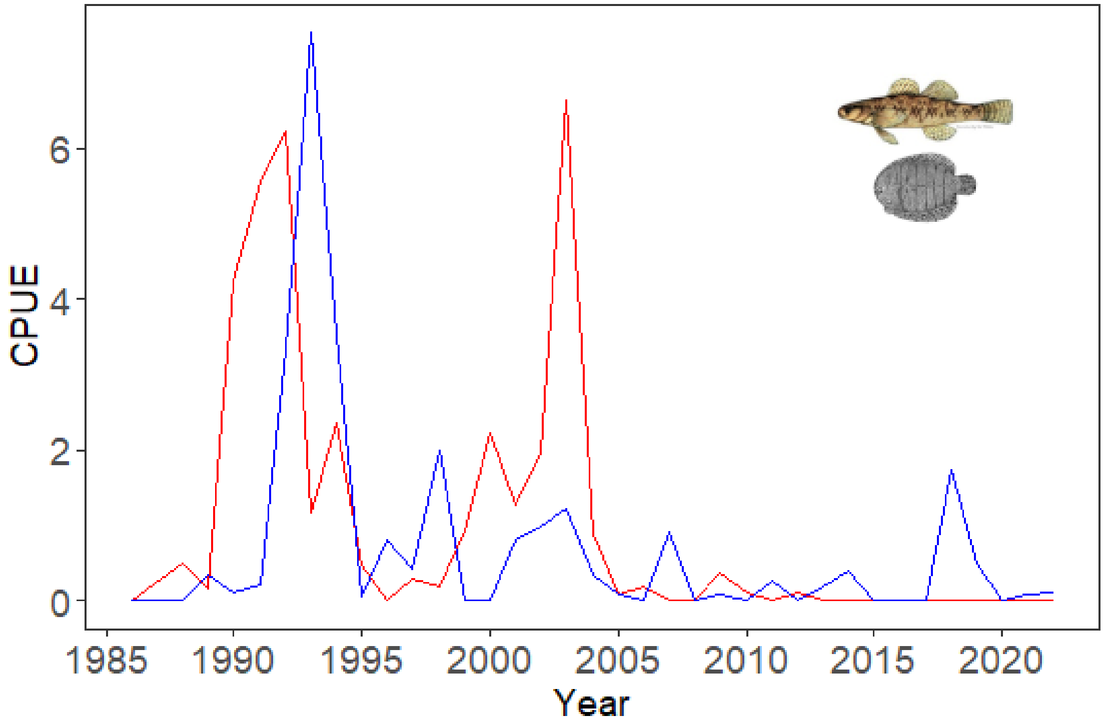


Figure 170. Trawls. Annual Averages. *Etheostoma olmstedi* (blue) and *Trinectes maculatus* (red). River Station (9).

Table 20. Mean catch per trawl of selected adult and juvenile fishes for all months at Sites 7, 9, and 10 combined. 1984-2022.

Year	All Species	White Perch	All Alosa Sp.	Blueback Herring	Alewife	Gizzard Shad	Bay Anchovy	Spottail Shiner	Brown Bullhead	Blue Catfish	Channel Catfish
2022	175.7	133.6	5.2	3.4	1.1	6.2	10.0	14.1	0.0	0.6	0.0
2021	106.1	72.1	7.5	2.9	3.1	0.1	1.2	10.5	0.0	0.8	0.0
2020	343.9	313.2	1.6	0.2	1.2	0.4	0.0	21.3	0.1	1.6	0.1
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	0.3	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 21. Mean catch per trawl of adult and juvenile fishes in all months at each station.

Year	7	9	10
2022	148.7	7.9	370.6
2021	261.8	11.8	54.3
2020	789.4	29.2	17.0
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

Table 22. The number of trawls per station in each month at Stations 7, 9, and 10 in each year.

Year	Station	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2022	10	0	0	1	2	2	2	2	1	0	0	0
2022	7	0	0	1	2	2	2	2	1	0	0	0
2022	9	0	0	1	2	2	2	2	1	0	0	0
2021	10	0	0	1	2	2	2	2	1	0	0	0
2021	7	0	0	1	2	2	2	2	1	0	0	0
2021	9	0	0	1	2	3	2	2	1	0	0	0
2020	10	0	0	0	0	0	2	0	0	0	0	0
2020	7	0	0	0	0	0	2	2	1	0	0	0
2020	9	0	0	0	0	0	2	2	1	0	0	0
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

Year	Station	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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

Year	Station	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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

Year	Station	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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

Seines

Overall Patterns

The long-term trend of seine catches shows a stable pattern of catches amidst inter-annual variability (Table 23, Figure 172), with 2022 collecting a high mean abundance of all species like 2022. Although not as high as 2021, 2022 is still in the top 5 years of mean abundance for all species. A high abundance of Alewife drove peaks in 1994 and 2004 and high catch rates in 1991 were driven by Blueback Herring (Table 23). The most abundant species in seine catches in 2022 was Banded Killifish, like 2021. Banded Killifish CPUE was like other elevated years since 2005, when SAV established in the cove. The number of seine tows over the period of record is shown in Table 24.

Table 23. Mean Catch per Seine of Selected Adult and Juvenile Fishes at all Stations and all Months. 1985-2022.

Year	All Species	White Perch	Banded Killifish	Blueback Herring	Alewife	All Alosa Sp	Spottail Shiner	Inland Silverside
2022	243.6	7.8	130.1	10.1	0.8	11.9	2.0	26.8
2021	327.8	19.9	231.1	0.7	0.8	5.2	4.1	17.6
2020	139.4	8.9	70.2	0.0	5.8	11.2	1.7	5.8
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	0.1	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	20.0
1985	120.2	36.8	11.7	0.0	0.1	0.2	13.2	29.3

Table 24. The number of seines in each month at Station 4, 4B, 6, and 11 in each year. 1985-2022.

Year	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2022	4	0	0	0	1	2	2	0	0	0	0	0	0
2022	6	0	0	0	1	2	2	2	2	1	0	0	0
2022	11	0	0	0	1	2	2	2	2	1	0	0	0
2022	4B	0	0	0	1	2	2	2	2	1	0	0	0
2021	4	0	0	0	1	2	2	2	1	0	0	0	0
2021	6	0	0	0	1	2	2	2	1	0	0	0	0
2021	11	0	0	0	1	2	2	2	2	1	0	0	0
2021	4B	0	0	0	1	2	2	2	2	1	0	0	0
2020	4	0	0	0	0	0	0	2	2	0	0	0	0
2020	6	0	0	0	0	0	0	2	2	1	0	0	0
2020	11	0	0	0	0	0	0	2	2	1	0	0	0
2020	4B	0	0	0	0	0	0	2	2	1	0	0	0
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

Year	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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

Year	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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

Year	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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

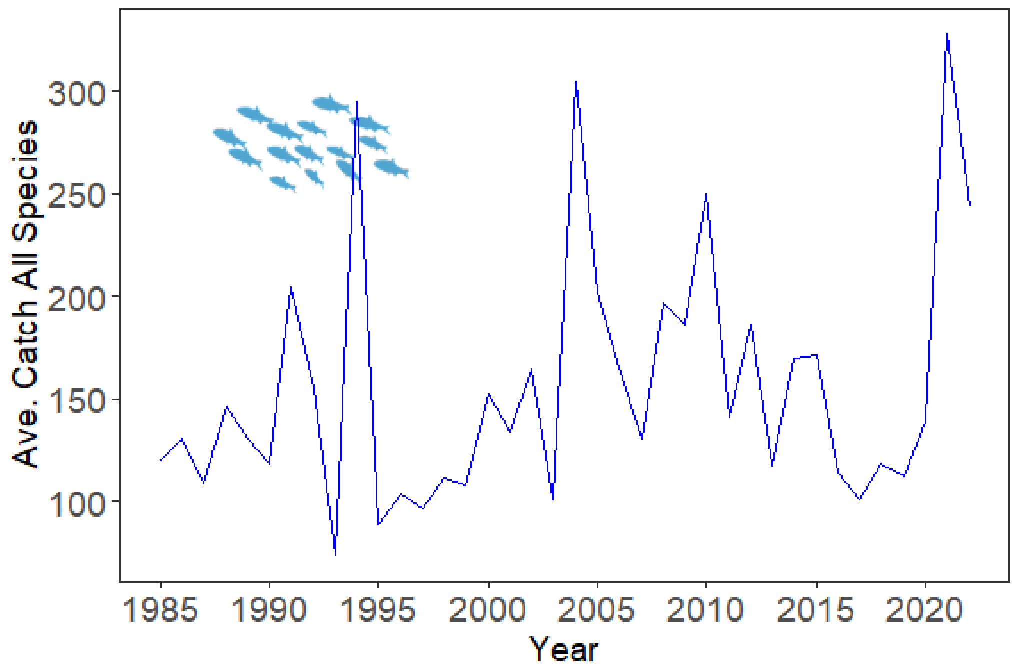


Figure 171. Seines. Annual Average over Stations 4, 4A, 6, and 11. All Species. 1985-2020.

Banded Killifish and White Perch have been the dominant species in seine samples throughout the survey. In 2022, the general trend of decreasing White Perch catches and increasing Banded Killifish catches over the period of record continued (Figures 172 and 173). However, White Perch CPUE may have leveled out in recent years and Banded Killifish remained high in 2022. The decrease in White Perch seen in seine catches is an indication of the shifted ecosystem state to an SAV dominated system, since Banded Killifish prefers SAV habitat, while White Perch prefers open water. In previous years we thought that the leveling out of both trends was indicative of a new stable state; however, Banded Killifish have continued to have elevated CPUE as in 2021. It appears that Banded Killifish may have high population numbers every 10 years or so, punctuated by peaks in 1994, 2004, 2010, and 2020. This could be indicative of long-term trends in their population.

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. Although CPUE was elevated in the mid 2000s, it declined again in 2015 and remained low (albeit higher than pre-SAV numbers) until 2021. This may be directly coupled to the extent of SAV in the cove during these years and a period of high freshwater discharge. Future work should investigate if annual SAV extent since establishment is correlated with Banded Killifish CPUE and/or other environmental parameters.

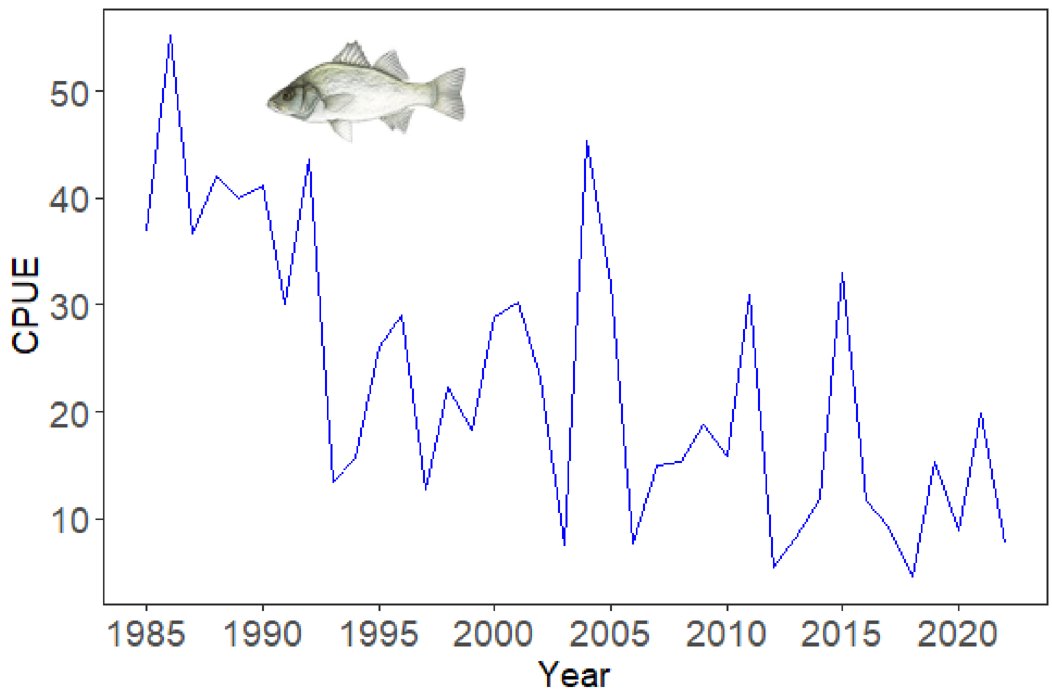


Figure 172. Seines. Annual Average Sites 4, 4A, 6, and 11. *Morone americana*. 1985-2022.

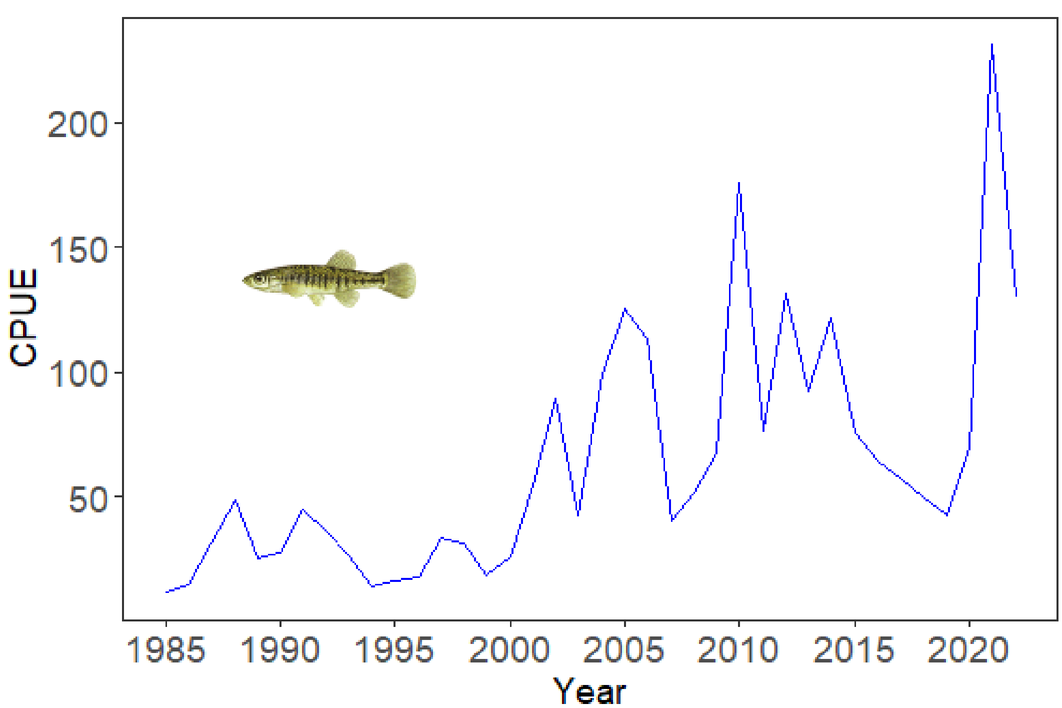


Figure 173. Seines. Annual Average Sites 4, 4A, 6, and 11. *Fundulus diaphanus*. 1985-2022.

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 174). Typically, less than 10 of either species were captured in a single sample. Both Alewife and Blueback Herring are 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. The moratorium (on fishing) may result in an increase in river herring over time. We added the category ‘all Alosa sp.’ to figure 174 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, than just based on Alewife and Blueback Herring findings. For example, relatively high peaks in Alosines have been found in 2007, 2010, 2015, 2018, and 2019. In 2020 a declining trend started that has continued through 2021. However, now in 2022 a slight increase was seen in Blueback Herring and all *Alosa* species. 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). Moderate levels of spawning adults were collected again in 2019, and 2020 could not be sampled because the spawning season of River herring occurred during the lockdown in response to the COVID-19 pandemic. In 2021, River Herring sampling recommenced, and we saw elevated numbers of Alewife in Accotink Creek, potentially continuing this 3-year trend in peak abundance. In 2022, numbers were diminished in Accotink Creek again and Pohick had abundances like those seen since 2018. Further details may be found in our Anadromous report for 2022.

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 175). Highest peaks occurred in 1999 and 2004 for Inland Silverside and Spottail Shiner respectively (Figure 175). After these high peaks, Inland Silverside remained relatively abundant with small peaks in 2006, 2008, 2012, 2017. In 2021, we recorded the highest abundances of Inland Silversides since the 1999 peak with abundances continuing to increase in 2022. Spottail Shiner decreased in 2022 and CPUE is consistent with that observed since 2006.

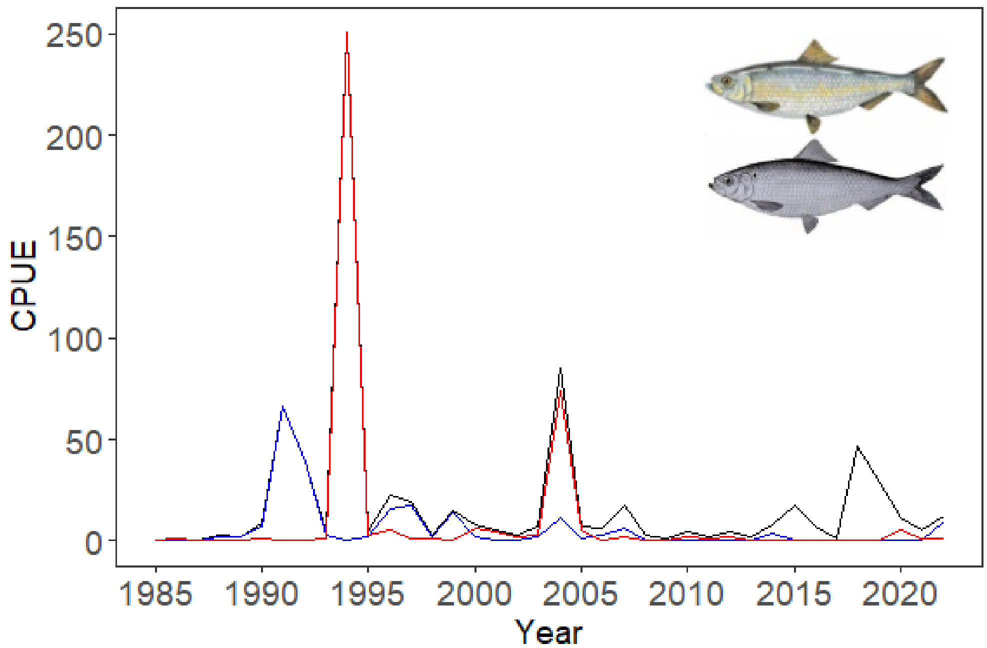


Figure 174. Seines. Annual Average over 4, 4A, 6, and 11 Sites. *Alosa aestivalis* (blue), *A. pseudoharengus* (red), and all *Alosa sp.* (black; *A. aestivalis*, *A. pseudoharengus*, *A. mediocris*, *A. sapidissima*, and unidentified Herring and Shad species). 1985-2022.

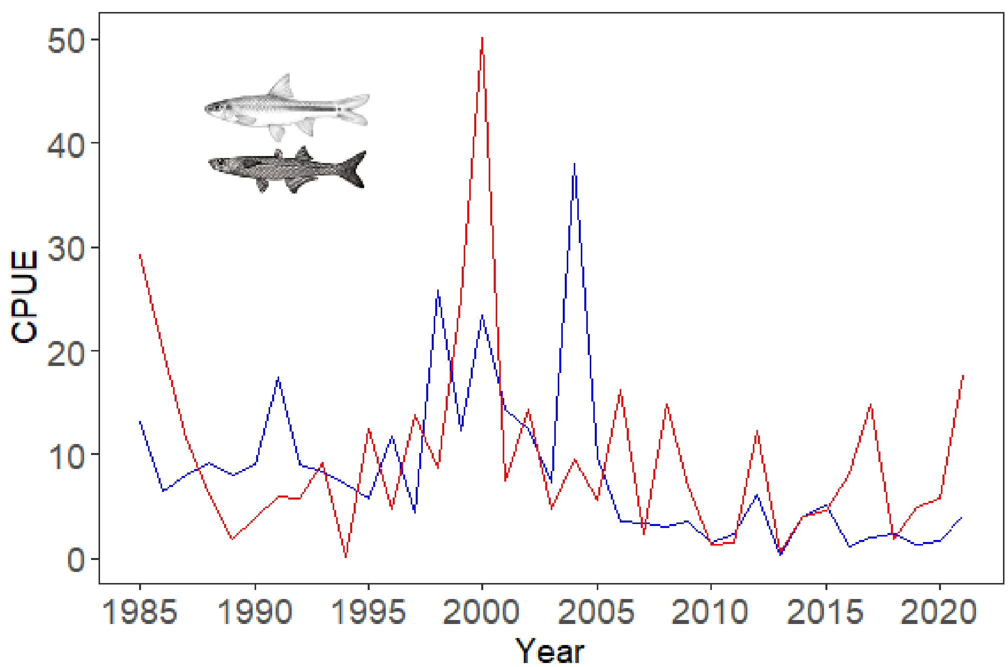


Figure 175. Seines. Annual Average over 4, 4A, 6, and 11 Sites. *Notropis hudsonius* (blue) and *Menidia beryllina* (red). 1985-2022.

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 176). 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 was present within the SAV beds as well (Figure 177). In 2022, White Perch CPUE was > 3 individuals, demonstrating their continued presence near SAV habitat. A species consistently sampled at moderately high levels with the fyke nets is Banded Killifish, which benefits from extensive SAV beds as habitat (Figure 178). However in 2022, Banded Killifish CPUE was the lowest observed in Fykes with the exception of 2018. Fyke nets efficiently sample SAV beds, and are usually dominated by SAV-associated species like Banded Killifish and Sunfishes. Sunfish CPUE also decreased in 2022 in our Fyke collections mirroring the trend seen in Banded Killifish, but was greater than Banded Killifish CPUE (Table 25, Figure 179). 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 26.

Inland Silverside typically have a variable record within the SAV-beds as represented by the fyke net catches; however, they were a common species this year exhibiting greater CPUE than Banded killifish. While inland silversides are not concentrated in SAV beds, they have remained moderately abundant throughout the Cove and the survey when all gear is considered.

After 2018 yielded the lowest abundance in fyke nets for the period of record, catches were up to normal levels again in 2019 and continued increasing in 2021; however, in 2022 CPUE decreased to low levels observed in 2013 and 2016 (Table 25, Figure 176). 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 (2012-2022). Future quantitative analysis of this trend similar to what we suggested for Seine collections is warranted. Collections were dominated by sunfishes again in 2022, 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 and likely lower density of SAV associated species. Other species that are collected with the fyke nets include native catfishes, such as the Brown Bullhead (Figure 180); however none were collected in 2022. Typically, we find the invasive Goldfish (Figure 181) and Largemouth Bass (Figure 182) as well, but neither species was collected this year.

Table 25. Mean Catch per Fyke of Selected Adult and Juvenile Fishes at all Sites and all Months.

Year	All Species	Sunfish	Banded Killifish	Inland Silverside	Tesselated Darter	Brown Bullhead	Largemouth Bass	Goldfish
2022	26.1	7.5	4.9	6.8	1.1	0.0	0.0	0.0
2021	74.9	29.9	16.7	22.7	1.7	0.1	0.0	3.0
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	0.1	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 26. The number of fykes in each month at Site Fyke 1 and Fyke 2 in each year. 2012-2022.

Year	Site	4	5	6	7	8	9
2022	Fyke 1	1	2	2	2	2	1
2022	Fyke 2	1	2	2	2	2	1
2021	Fyke 1	0	1	0	1	2	1
2021	Fyke 2	0	1	1	1	2	1
2019	Fyke 1	0	2	2	2	2	1
2019	Fyke 2	0	2	2	2	2	1
2018	Fyke 1	1	2	2	2	2	1
2018	Fyke 2	1	2	2	2	2	1
2017	Fyke 1	0	2	2	2	2	1
2017	Fyke 2	0	2	2	2	2	1
2016	Fyke 1	1	2	2	2	2	1
2016	Fyke 2	1	2	2	2	2	1
2015	Fyke 1	1	2	1	2	2	1
2015	Fyke 2	1	2	1	2	2	1
2014	Fyke 1	1	2	2	2	2	1
2014	Fyke 2	1	2	2	2	2	1
2013	Fyke 1	0	2	2	2	2	1
2013	Fyke 2	0	2	2	2	2	1
2012	Fyke 1	0	0	1	2	2	1
2012	Fyke 2	0	0	1	2	2	1

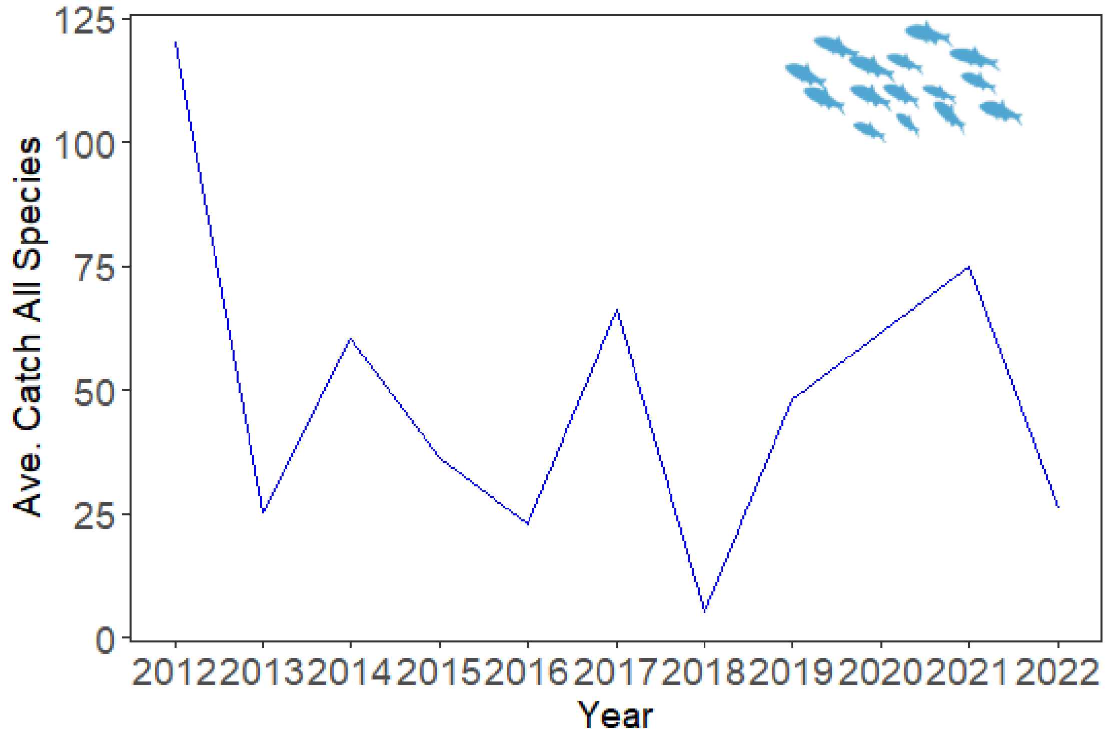


Figure 176. Fykes Annual Average over Sites Fyke 1 and Fyke 2. All Species. 2012-2022.

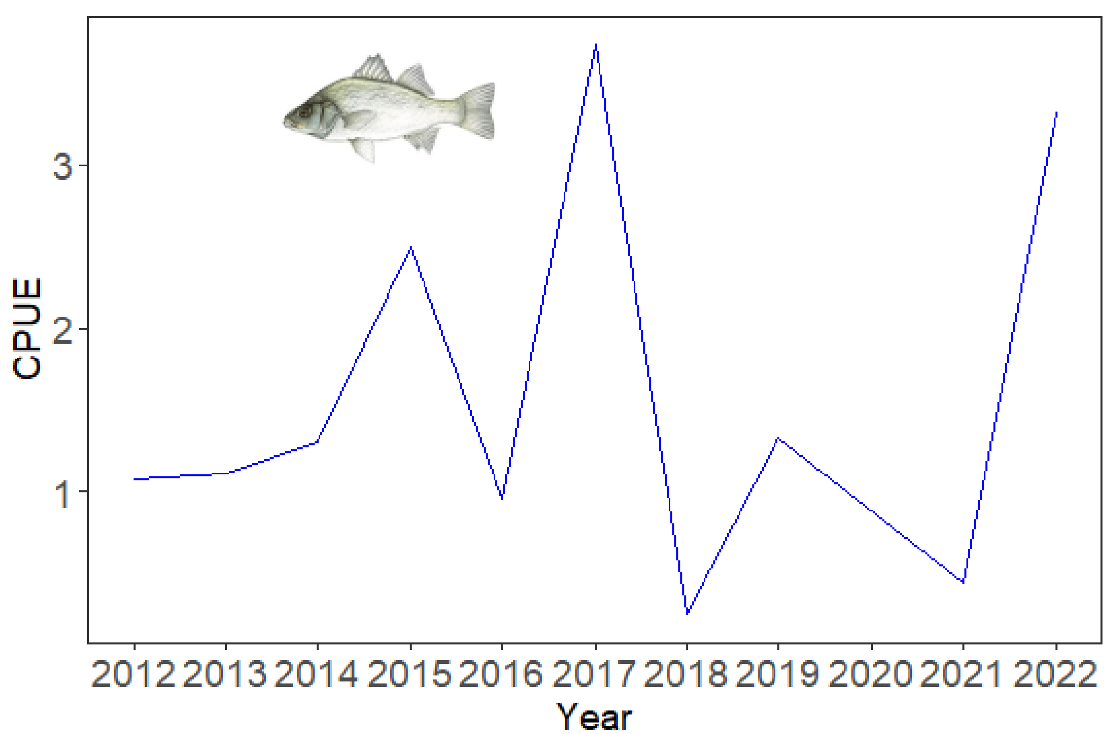


Figure 177. Fyke Annual Average Sites Fyke 1 and Fyke 2. *Morone americana*. 2012-2022.

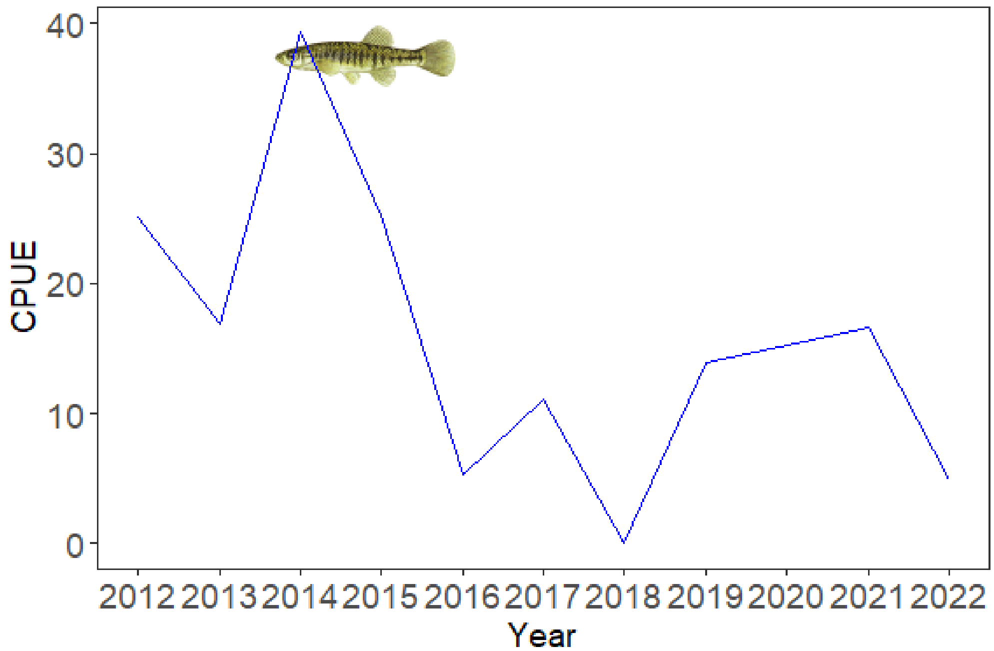


Figure 178. Fyke Annual Average Stations Fyke 1 and Fyke 2. *Fundulus diaphanus*. 2012-2022.

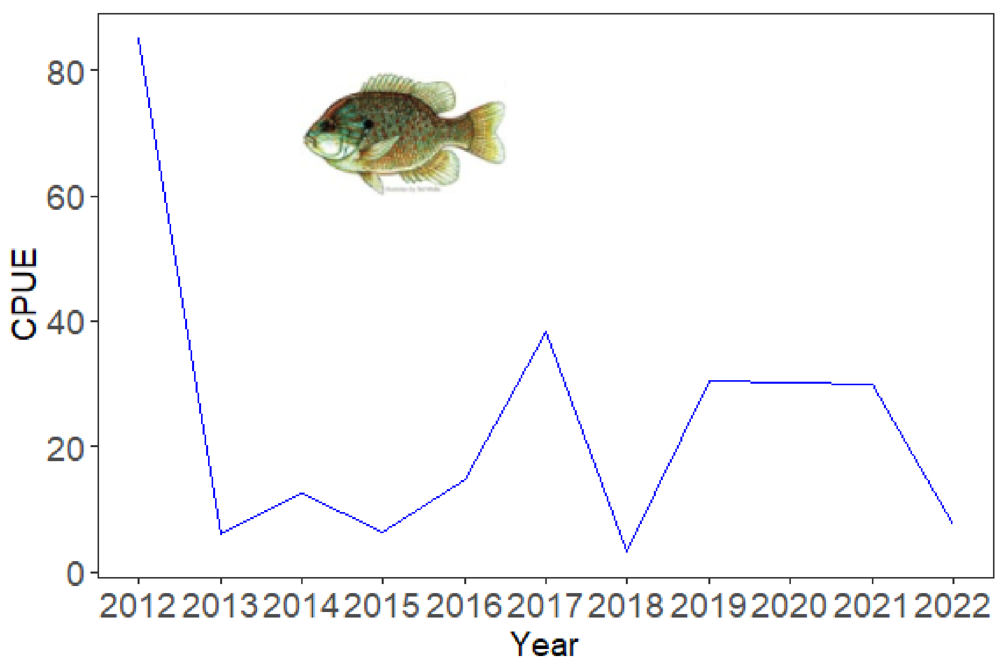


Figure 179. Fykes Annual Average over Fyke 1 and Fyke 2 Stations. All *Lepomis sp.* (blue). 2012-2022.

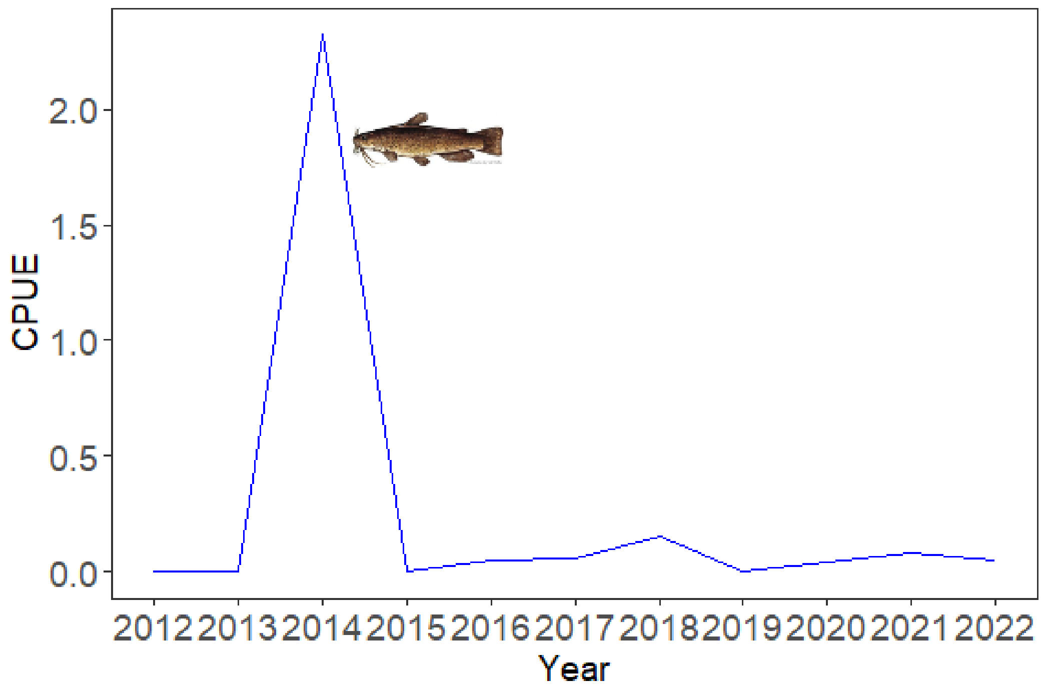


Figure 180. Fykes Annual Average over Fyke 1 and Fyke 2 Stations. *Ameiurus nebulosus* (blue). 2012-2022.

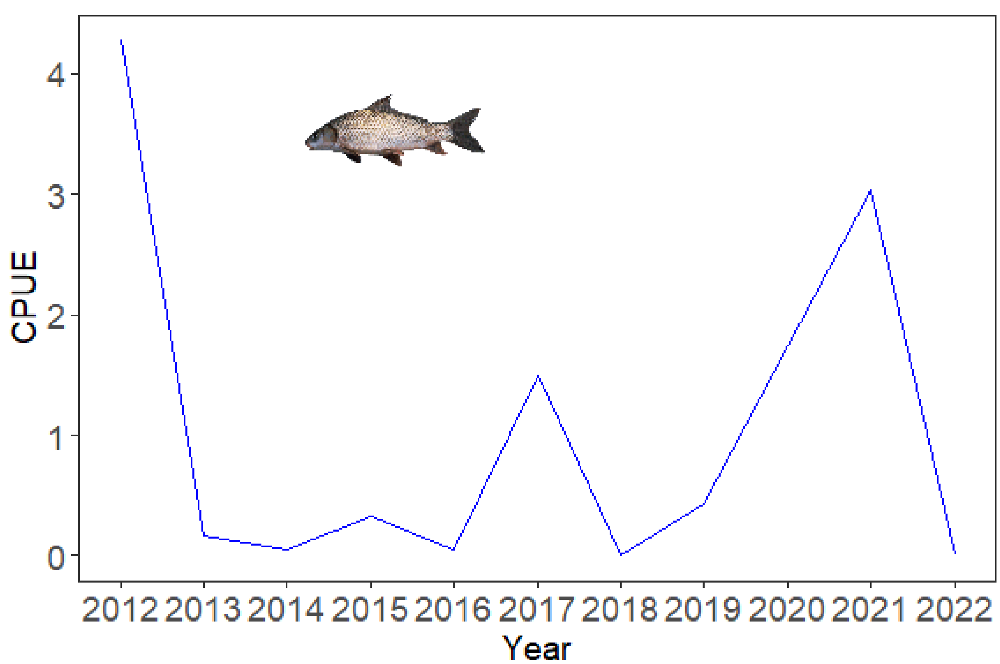


Figure 181. Fykes Annual Average over Fyke 1 and Fyke 2 Sites. *Carassius auratus* (blue). 2012-2022.

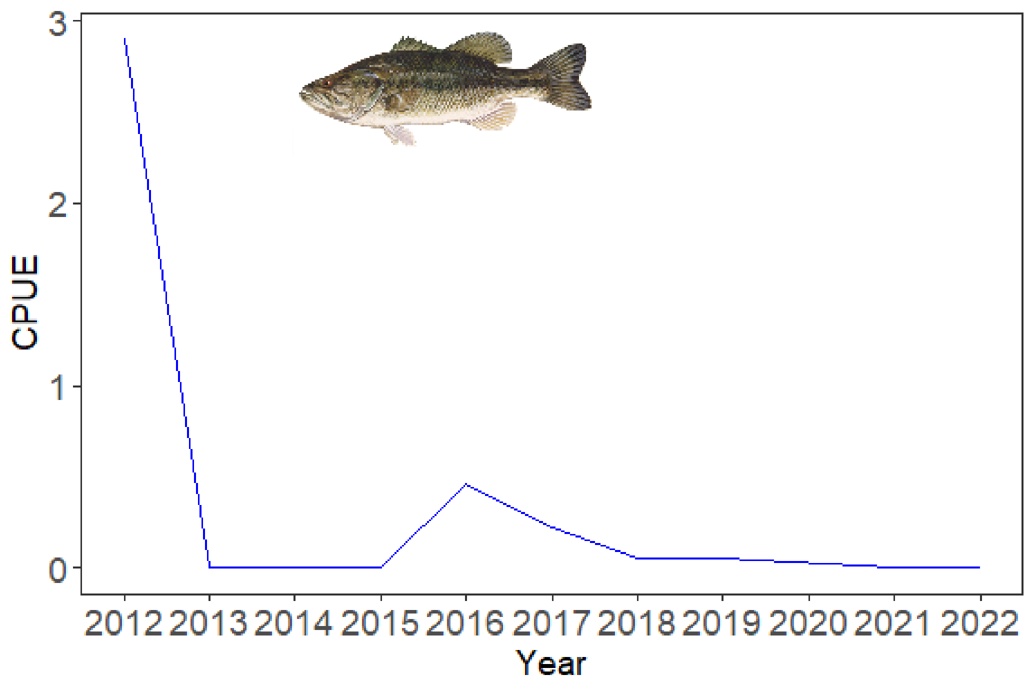


Figure 182. Fykes Annual Average over Fyke 1 and Fyke 2 Sites. *Micropterus salmoides* (blue). 2012-2022.

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, especially in seine samples. However, CPUE seeems to be tied to actual SAV extent and needs to be investigated further. A detailed multivariate analysis of the community structure shifts in the Gunston Cove fish community since the start of the Gunston Cove survey was published (De Mutsert et al. 2017), but an update for the last 20 years will be needed soon. 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 at all sites, 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, but we are collecting them further into the cove than was seen post establishment. We colletced a couple of native catfishes in trawls, but overall abunadnces were low. More fyke net collections or electrofishing samples 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. We are aquiring an electrofishing boat for George Mason and hope to add this survey to this study in the future to better understand the fish community of Gunston Cove.

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 anadromous species does come up to tidal freshwater areas to spawn, and we find juvenile Striped Bass in our seine and trawl collections. Furthermore, resident freshwater Striped bass have been found and could occur within or near our study area.

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 were observed, but these numbers have since decreased back to low levels.

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 2022 (Figure 183). In this index, calculated as $1-(\Sigma\ (ni/N)^2)$, the communities with higher diversity have higher values (approaching 1). The Simpson's Index of Diversity was 0.782 in 2022, which is higher than recent years and similar to the high numbers seen from 2015 - 2019. Gunston Cove harbors a diverse fish community characteristic of Potomac River tributaries.

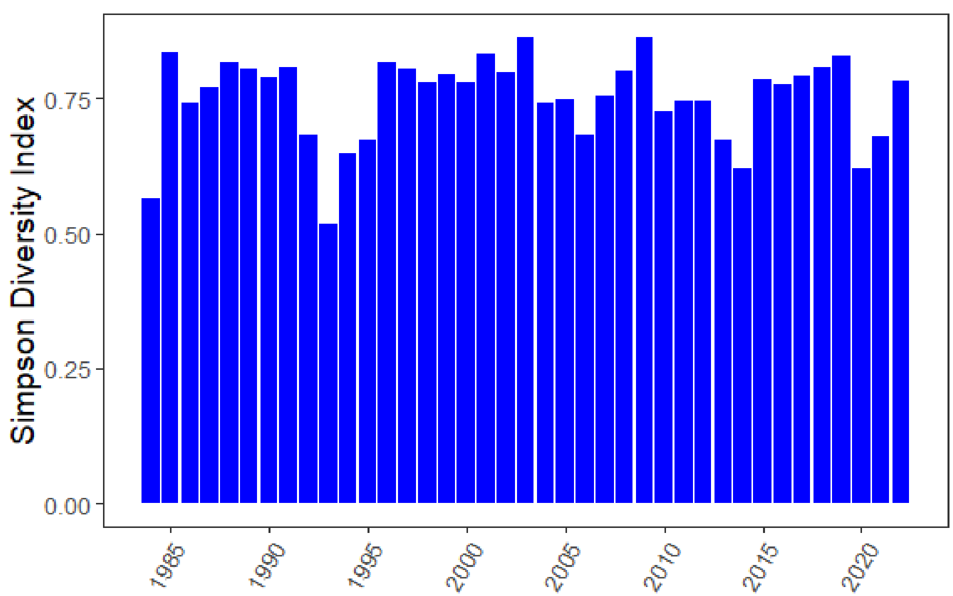


Figure 183. Simpson Diversity Index of fish species collected in Gunston Cove all years.

Summary

In 2022 ichthyoplankton was dominated by clupeids, most of which were Gizzard Shad and unidentified Clupeids. However, Blueback Herring and Alewife made up 8% each of total ichthyoplankton collections. White Perch was also dominant representing 13% of all ichthyoplankton collected. 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 spawn from March – May, above the head of the tide. Following spawning, larvae drift into tidal freshwaters like Gunston Cove where they develop into juveniles prior to out-migration. Therefore, Gunston Cove is a valuable nursery habitat for imperiled River Herring.

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), that has leveled off in recent years. 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. Future work slated for the post 2025 season, should focus on a multivariate community assessment for the last 20 years to update the work of De Mutsert et al. 2017)

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 down again in 2022 and may be a result of less SAV. As mentioned previously, a quantitative analysis of SAV coverage with Fyke and Banded Killifish CPUE is warranted. 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 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). We observed another peak in River Herring spawning abundance in 2021 and Blueback Herring made up 1.93% and 4.16% of trawl and seine collections in 2022. However, 2022 spawners were back to lower levels in both Accotink and Pohick creeks. 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: 2016-2022

Benthic invertebrates have been monitored in a consistent fashion since 2009. Data from 2016-2022 are assembled below (Figures 184&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 chironomids (midge larvae) are declining; however, this trend has not been consistent the past four years (2019, 2020, 2021, 2022) and may represent another change to the system. 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 and all previous years 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 186). 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 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. Only two Turbellaria were found in 2022 (both from GC9 in July), and only one Hirundinea (at GC7 in July). Bivalves and Gastropods also occur in low numbers at both sites, with approximately the same average number of Gastropods across sites and years, although only two Gastropods were recorded in 2022 (both from GC9 in June). 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.

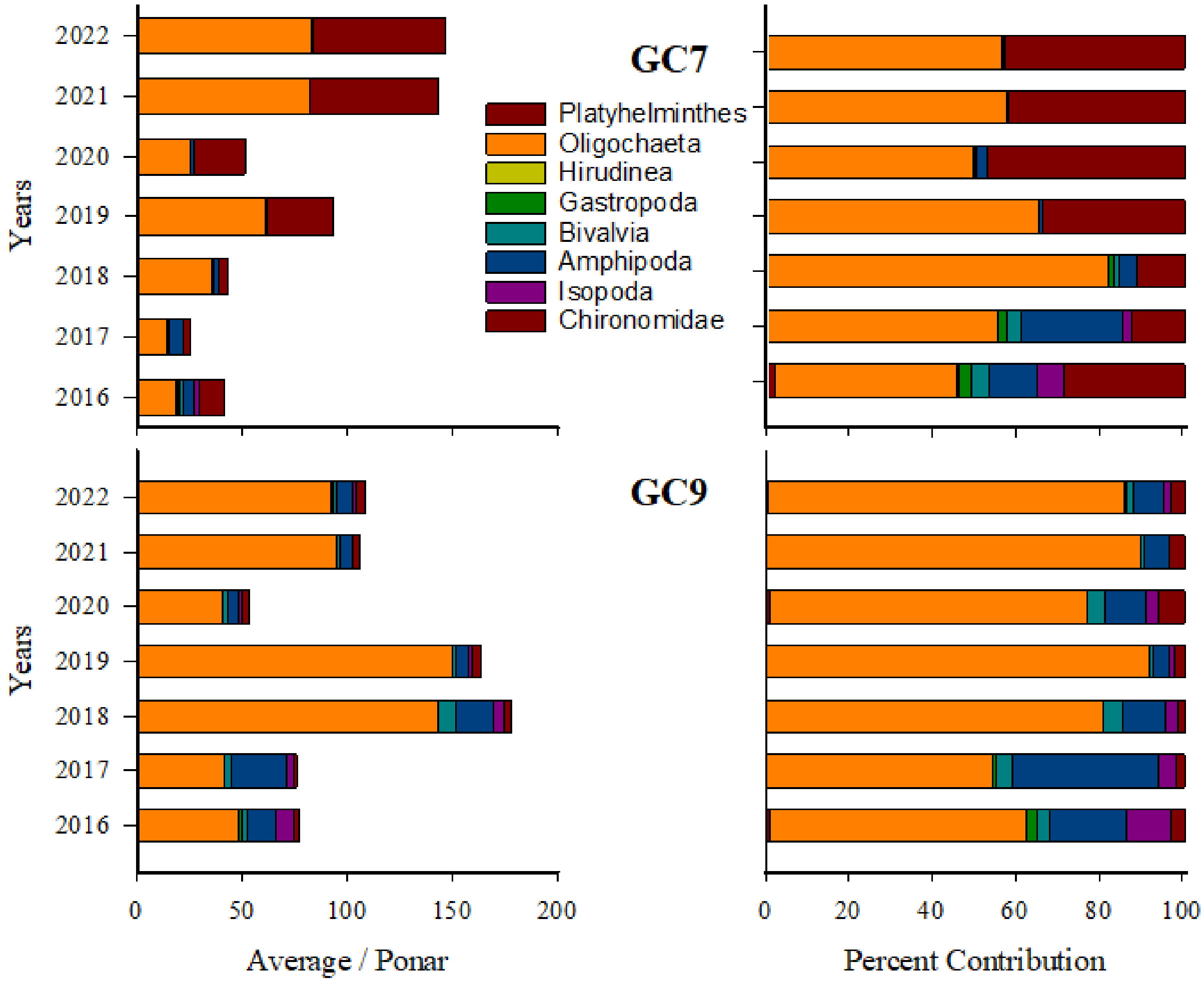


Figure 184. Average number per ponar sample (Left) and percent contribution (Right) of the eight dominant benthic invertebrate taxa in Gunston Cove embayment samples collected between 2016 and 2022 separated by site and year. Note the dominance of the Oligochaeta (worms).

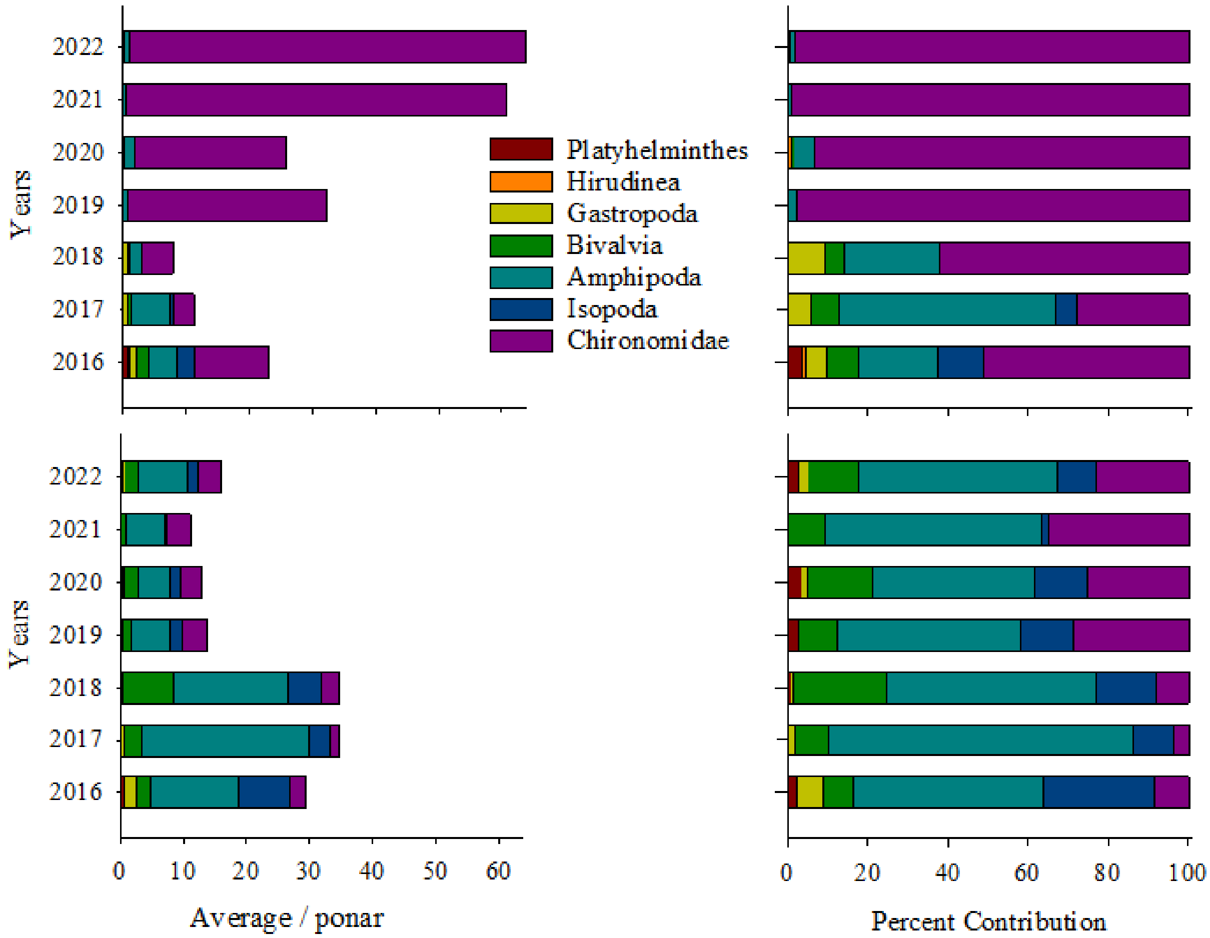


Figure 185. Without Oligochaeta, average number per ponar sample (Left) and percent contribution (Right) of the dominant benthic invertebrate taxa in Gunston Cove embayment samples collected between 2016 and 2022 separated by site and year.

H. Submersed Aquatic Vegetation (SAV) Trends: 1994-2022

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/. Maps of SAV coverage in the Gunston Cove area are available on the web site for the years 1994-2022 except for 2001, 2011, and 2018. 2018 was a high flow year with many substantial storms during the SAV growing period. Although the standardized data was not available, it was obvious that SAV was much reduced in 2018. In 2019 and 2020, average Secchi disk transparency increased to pre-2018 levels and SAV rebounded to near record levels (Figure 186). However, in 2021 SAV coverage declined somewhat apparently due to decreased water clarity reflected by a decrease in Secchi depth. Water clarity declined further in 2022, and so did SAV coverage. Note the strong correlation between summer Secchi depth and SAV coverage (Fig. 186).

There is some cause for concern here because Secchi depths have been decreasing since 2017 and now SAV coverage seems to be shrinking, although still well above pre-2005 values. And phytoplankton has not increased greatly so it seems that inorganic sediment, either from upstream sources in the watershed or from resuspension within the cove is responsible for the decreased transparency,

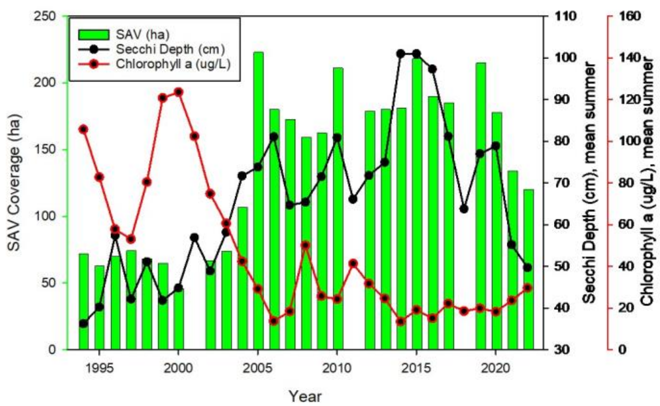


Figure 186. Gunston Cove SAV Coverage. Graphed with average summer (June-September) Depth-integrated Chlorophyll a (µg/L) and Secchi Depth (cm) measured at Station 7 in Gunston Cove.

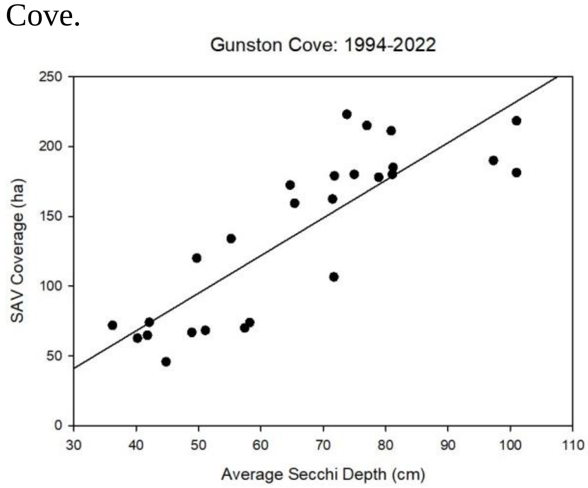


Figure 187. Correlation between Average Summer Secchi Depth (cm) and SAV Coverage (ha).

LITERATURE CITED

Bigelow, H.B. and W.C.Schroeder. 1953. Fishes of the Gulf of Maine. Fishery bulletin No. 74, Vol. 53. U.S. Government Printing Office. Washinton, D.C. 577 pp.

Carter, V., P.T. Gammon, and N.C. Bartow. 1983. Submersed Aquatic Plants of the Tidal Potomac River. Geological Survey Bulletin 1543. U.S. Geological Survey. 63 pp.

Chesapeake Bay Program. 2006 Ambient water quality criteria for dissolved oxygen, water clarity, and chlorophyll *a* for the Chesapeake Bay and its tidal tributaries. 2006 Addendum. Downloaded from Bay Program website 10/13/2006.

Cummings, H.S., W.C. Purdy, and H.P. Ritter. 1916. Investigations of the pollution and sanitary conditions of the Potomac watershed. Treasury Department, U.S. Public Health Service Hygienic Laboratory Bulletin 104. 231 pp.

Dahlberg, M.D. 1975. Guide to coastal fishes of Georgia and nearby states. University of Georgia Press. Athens, GA 187 pp.

De Mutsert, K., Sills, A., Schlick, C.J.C., and R.C. Jones. 2017. Successes of restoration and its effects on the fish community in a freshwater tidal embayment of the Potomac River, USA. Water 9(6), 421; doi:10.3390/w9060421

Douglass, R.R. 1999. A Field Guide to Atlantic Coast Fishes: North America (Peterson Field Guides). Houghton Mifflin Harcourt, Boston. 368 pp.

Eddy, S. and J.C. Underhill. 1978. How to know the freshwater fishes. 3rd Ed. W.C. Brown Co. Dubuque, IA. 215 pp.

Hildebrand and Schroeder. 1928. Fishes of the Chesapeake Bay. U.S. Bureau of Fisheries Bulletin 53, Part 1. Reprinted 1972. T.F.H. Publishing, Inc. Neptune, NJ. 388 pp.

Hogue, J.J, Jr., R.Wallus, and L.K. Kay. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. Technical Note B19. Tennessee Valley Authority. Knoxville, TN.

Huntley, M., K. Tande, and H.C. Eilertsen. 1987. On the trophic fate of *Phaeocystis pouchetii* (Hariot). Grazing rates of *Calanus hyperboreus* (Kroyer) on diatoms and different size categories of *Phaeocystis pouchetii*. J. Exp. Mar. Biol. Ecol. 110: 197-212.

Islam, S. 2001. Seasonal dynamics of micro-, nanno-, and picoplankton in the tidal freshwater Potomac River in and around Gunston Cove. Ph.Dissertation. George Mason University. 127 pp.

Jenkins, R.E. and N.M. Burkhead. 1994. The freshwater fishes of Virginia. American Fisheries Society. Washington, DC. 1080 pp.

Jones, P.W., F.D. Martin, and J.D. Hardy, Jr. 1978. Development of fishes of the Mid-Atlantic bight. Volumes I-VI. Fish and Wildlife Service, U.S. Department of the Interior. FWS/OBS-78/12.

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

Kelso, D.W., R.C. Jones, and P.L. deFur. 1985. An ecological study of Gunston Cove - 1984-85. 206 pp.

Kraus, R.T. and R.C. Jones. 2011. Fish abundances in shoreline habitats and submerged aquatic vegetation in a tidal freshwater embayment of the Potomac River. Environmental Monitoring and Assessment. Online: DOI 10.1007/s10661-011-2192-6.

Lippson, A.J. and R.L. Moran. 1974. Manual for identification of early development stages of fishes of the Potomac River estuary. Power Plant Siting Program, Maryland Department of Natural Resources. PPSP-MP-13.

Loos, J.J., W.S. Woolcott, and N.R. Foster. 1972. An ecologist's guide to the minnows of the freshwater drainage systems of the Chesapeake Bay area. Association of Southeastern Biologists Bulletin 19: 126-138.

Lund, J.W.G., C. Kipling, and E.C. LeCren. 1958. The inverted microscope method of estimation algal numbers and the statistical basis of estimations by counting. Hydrobiologia 11: 143-170.

Mansueti, A.J. and J.D. Hardy, Jr. 1967. Development of fishes of the Chesapeake Bay region: an atlas of egg, larvae and juvenile stages: Part 1. Natural Resources Institute. University of Maryland. 202 pp.

Merritt, R.W. and K.W. Cummins. 1984. An introduction to the aquatic insects of North America. 2nd edition. Kendall/Hunt Publishing Co., Dubuque, IA. 722 pp.

Page, L.M., and B.M. Burr. 1998. A Field Guide to Freshwater Fishes: North America North of Mexico (Peterson Field Guides). Houghton Mifflin Harcourt, Boston. 448 pp.

Pennack, R.W. 1978. Fresh-water invertebrates of the United States. 2nd ed. Wiley-Interscience. New York, NY.

Schloesser, R.W., M.C. Fabrizio, R.J. Latour, G.C. Garman, G.C., B. Greenlee, M. Groves and J. Gartland. 2011. Ecological role of blue catfish in Chesapeake Bay communities and implications for management. American Fisheries Society Symposium 77:369-382.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Bulletin 184. Fisheries Research Board of Canada. Ottawa, Canada. 966 pp.

Standard Methods for the Examination of Water and Wastewater. 1980. American Public Health Association, American Waterworks Association, Water Pollution Control Federation. 15th ed. 1134 pp.

Thorp, J.H. and A.P. Covich, eds. 1991. Ecology and classification of North American Freshwater Invertebrates. Academic Press. San Diego, CA. 911 pp.

Wetzel, R.G. 1983. Limnology. 2nd ed. Saunders. 767 pp.

Wetzel, R.G. and G.E. Likens. 1991. Limnological analyses. 2nd ed. Springer-Verlag. 391 pp.

Anadromous Fish Survey of Pohick and Accotink Creeks

2022

Final Report
December 2023

By

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Background

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

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

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 2022 sampling are presented below. Since the 2015 report, we have included a summary of 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 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 out drifting 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. After missing 2020 as a result of COVID-19, we have continued this sampling protocol in 2021 and 2022 in Pohick and Accotink Creeks.

Methods

We conducted weekly sampling trips from March 10 to May 12 in 2022. 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:

$$\text{Distance (m)} = \text{Difference in Counts} * \text{Rotor Constant (57560)}/999999$$

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

$$\text{Volume (m}^3\text{)} = ((3.14 * (\text{Net Diameter } (0.25)^2)/4) * \text{Distance}$$

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:

$$\text{Depth (m)} \times \text{Width (m)} \times \text{Velocity (m/s)} = \text{Discharge (m}^3\text{/s)}$$

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. During high rainfall events, block nets do not sample effectively and are dangerous to deploy and retrieve. Therefore, we completed larval sampling and creek profiles across all 10 weeks, but block nets were only set for six weeks (Table1).

Table 1. Sampling dates and procedures (Block Nets, Plankton Nets, and Creek Cross-Section [CS]) completed during each sampling event at each creek.

	Accotink				Pohick			
Date	**Block**	**Plankton**	**CS**	**YSI**	**Block**	**Plankton**	**CS**	**YSI**
3/10/2022	N	Y	Y	Y	N	Y	Y	Y
3/17/2022	Y	Y	Y	Y	Y	Y	Y	Y
3/23/2022	Y	Y	Y	Y	Y	Y	Y	Y
3/31/2022	Y	Y	Y	Y	Y	Y	Y	Y
4/6/2022	N	N	N	N	N	N	N	N
4/14/2022	Y	Y	Y	Y	Y	Y	Y	Y
4/21/2022	Y	Y	Y	Y	Y	Y	Y	Y
4/28/2022	Y	Y	Y	Y	Y	Y	Y	Y
5/5/2022	N	Y	Y	Y	N	Y	Y	Y
5/12/2022	Y	Y	Y	Y	Y	Y	Y	Y

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 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):

$$\text{Egg \#} = -90{,}098 + 588.1(\text{TL mm})$$

We used data from specimens where both standard length and total length was estimated to convert standard length to total length in cases where we had not measured total length. Our data resulted in the following conversion:

$$TL = 1.16SL + 6.$$

The regression had an R2 of 0.97. Since the nets were set 24 hours per week for 6 (144 hours) out of the 10-week season (7 days * 10 weeks * 24 hours in a day = 1680 season hours), 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:

$$\text{Total catch} / 144 \text{ hours} * 1680 \text{ hours} = \text{total abundance of spawners}$$

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 number 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 to funnel up-migrating herring into the opening of the net.

Results

Our creek sampling work in 2022 spanned a total of 10 weeks, during which we collected 36 ichthyoplankton samples, and 14 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 collected no adult Hickory Shad in Accotink Creek but collected 259 in Pohick Creek.

The abundance of confirmed Alosa larvae was lower than 2021 (n = 171), continuing a downward trajectory. The number of unidentified clupeid larvae was low (22 and 35 individuals in Accotink and Pohick respectively), 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 (as was the case this year), we generally have fewer unidentified larvae. We also collected 13 identified Gizzard Shad larvae. We found that most Alosa larvae consisted of Alewife larvae, followed by Hickory Shad, Gizzard Shad, and Blueback Herring (Table 2).

Table 2. Clupeid larvae count and density (#/m3), and adult counts and catch per unit effort (CPUE = number collected/total nets set [7]) from Accotink and Pohick creeks in 2022.

		Adult Count			**Adult CPUE**		
Species	**Larvae**	**Female**	**Male**	**All**	**Female**	**Male**	**All**
Accotink							
Blueback Herring	0	0	0	1	0	0	0.14
Hickory Shad	3	0	0	0	0	0	0
Alewife	20	11	11	46	1.57	1.57	6.57
Alosa sp.	0	0	0	0	0	0	0
Gizzard Shad	6	3	7	19	0.43	1.00	2.71
Mangled Clupeid	22	0	0	0	0	0	0
Pohick							
Blueback Herring	7	7	23	46	1.00	3.29	6.57
Hickory Shad	12	93	80	259	13.29	11.43	37.00
Alewife	128	16	57	173	2.29	8.14	24.71
Alosa sp.	1	0	0	1	0	0	0.14
Gizzard Shad	7	0	3	14	0	0.43	2.00
Mangled Clupeid	35	0	0	0	0	0	0

We measured creek discharge at the same locations and times where ichthyoplankton samples were taken. The creeks showed similar discharge patterns this year (Figure 2), with consistently higher discharge in Pohick Creek than in Accotink Creek, similar to 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 6.3 and 7.8 million cubic meters for Accotink and Pohick creeks, respectively (Table 3), which is similar to pre 2021 years. Larval density of Alewife exhibited a peak in Accotink Creek the first week of April (Figure 3a), while densities in Pohick creek were elevated from mid March to mid April (Figure 3a). Given the observed mean densities of larvae and the total discharge, the total production of Alewife larvae was estimated at 0.26 million and 2.15 million for Accotink Creek and Pohick Creek, respectively (Table 3). Larval density of Blueback Herring larvae were not collected in Accotink Creek and had peaks in mid April and May 1st in Pohick Creek (Figure 3b). Blueback

Herring larval density was much lower than Alewife and previous years, leading to total larval production estimates of 0 and 79,775 for Accotink Creek and Pohick Creek, respectively, compared to production greater than 1 million in previous years.

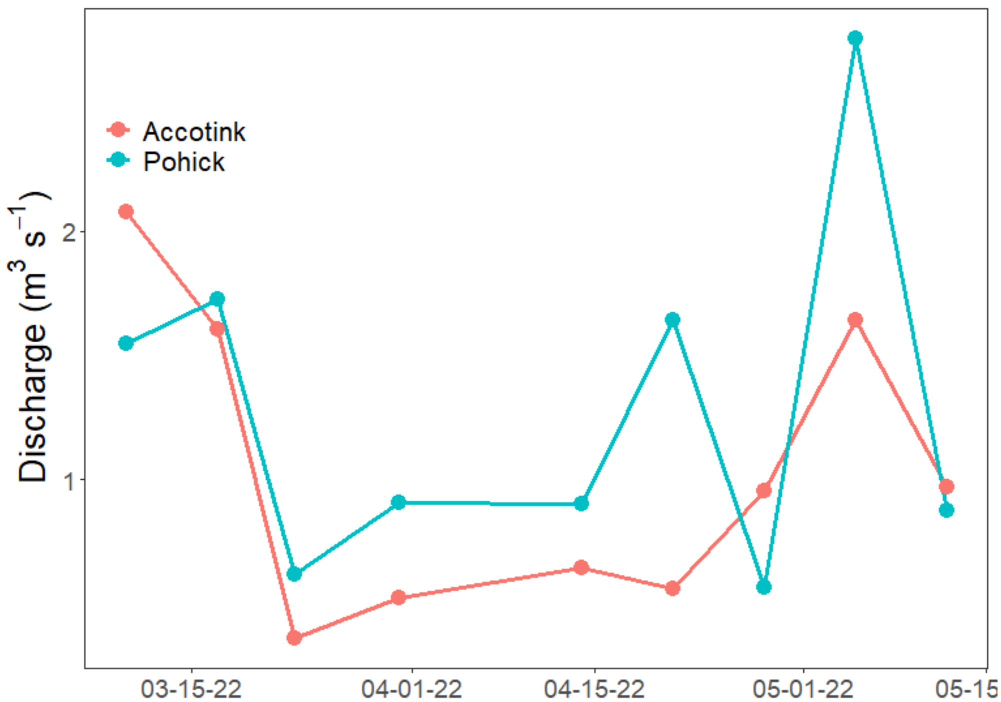

Figure 2. Discharge rate in m^3 s^{-1} measured in Pohick and Accotink creeks during 2022.

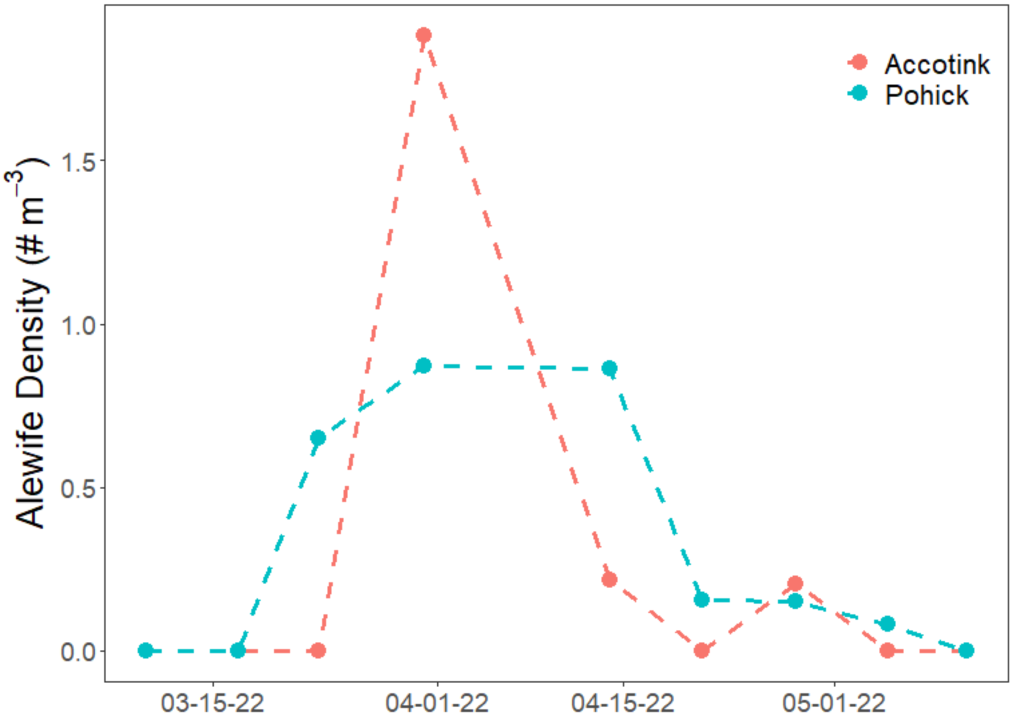

Figure 3a. Density of larval Alewife (*Alosa pseudoharengus*) observed in Pohick Creek and Accotink Creek in 2022.

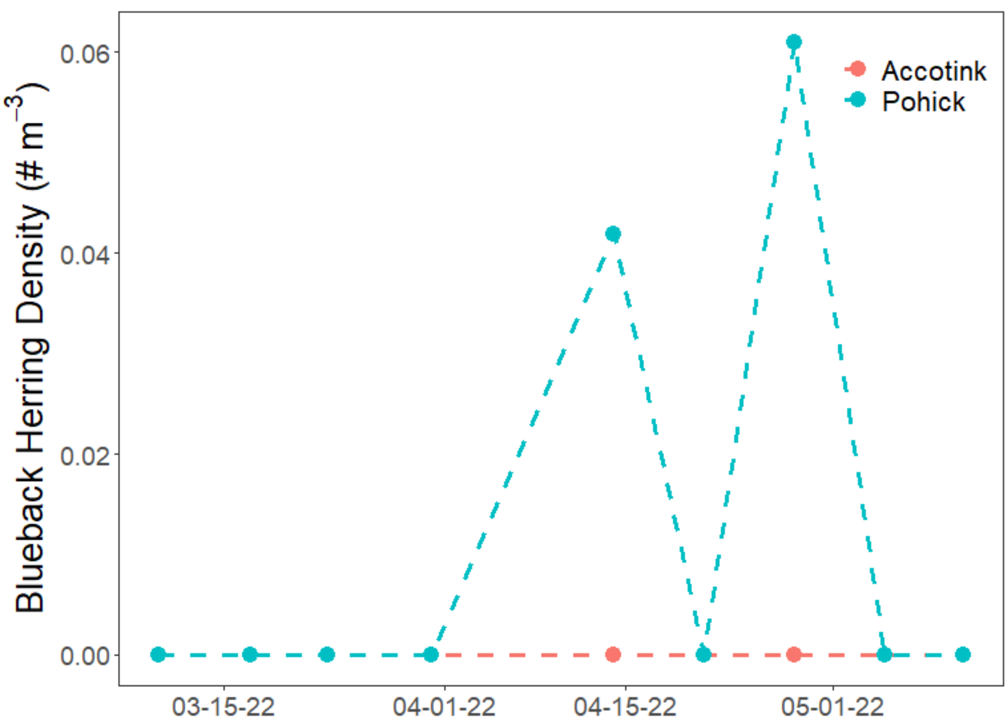

Figure 3b. Density of larval *Alosa aestivalis* in # m^-3& observed in Pohick Creek and Accotink Creek in 2022.

In the block nets, Alewife were collected in both creeks (Accotink = 46, Pohick = 173, Table 2), but the CPUE was much lower in Accotink Creek then in 2021 (Table 4, Figure 4). In Pohick creek this CPUE was like 2021 and 2019. Blueback Herring numbers were lower in Accotink Creek (n = 1) than in 2021, but higher in Pohick Creek (n = 46) (Table 2). For Alewife and Blueback Herring, higher numbers of male fish were collected. Skewed sex ratios in fish populations are common in *Alosa sp.* (Kissil 1974, Loesch and Lund JR 1977) and are not a problem as long as fecund females are present. The abundance of spawning Alewife was estimated to be 224 in Accotink Creek and 847 in Pohick Creek during the sampling period. Similar to the CPUE, this is lower than 2021 for Accotink Creek and similar to previous years for Pohick Creek. Overall, the estimated number of individual Blueback Herring were low, 7 and 224 spawners in Accotink and Pohick creeks respectively. Although these Blueback numbers are lower than recent years, they are still elevated above numbers at the start of the survey.

Table 3. Estimation of *Alosa pseudoharengus* and *A. aestivalis* fecundity and spawner abundance from Accotink and Pohick creeks during spring 2022.

Parameter	**Accotink**	**Pohick**
Mean discharge (m^3s^{-1})	1.037	1.283
Minimum discharge (m^3s^{-1})	0.359	0.563
Maximum discharge (m^3s^{-1})	2.077	2.777
Total discharge, (m^3)	6270355.662	7760692.288
Mean Alewife larvae density (m^3)	0.042	0.277
Total Alewife Larval Production	264403.561	2149793.452
Adult Alewife Mean Standard Length (mm)	229.464	225.271
Alewife Fecundity	75788.984	72947.703
Alewife Sex Ratio	0.250	0.091
Estimated number of female alewife	56.000	84.700
Estimated total number of alewife	224.000	847.000
Mean Blueback Herring larvae density (m^3)	0.000	0.010
Total Blueback Herring Larval Production	0.000	79774.792
Adult Blueback Herring Mean Standard Length (mm)	205.000	213.000
Blueback Herring Fecundity	59211.768	64632.639
Blueback Herring Sex Ratio	0.000	0.156
Estimated number of female Blueback Herring	0.000	41.481
Estimated total number of Blueback Herring	7.000	224.000

Discussion

Summary 2022

We caught 219 adult Alewife, 47 adult Blueback Herring, and 259 Hickory Shad. For Blueback Herring these numbers are much lower than usual and Hickory Shad numbers were higher (Figure 4). Both Alewife and Blueback Herring numbers were less than in 2021, but similar to previous years (Figure 4). The estimated size of the spawning population of Alewife is 1,071 fish in the Gunston Cove watershed in 2022. Estimated Blueback Herring abundance was lower than recent years (n = 231), but higher than what was observed prior to 2015. The greater abundance of fishes in Pohick Creek may have been driven by greater discharge in 2022, although the differences were not drastic. By receiving effluent for the Noman Cole pollution control plant, Pohick Creek is slightly warmer than Accotink Creek. This temperature difference may have created longer more desirable spawning conditions driving the higher numbers we observed in Pohick Creek. 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. There is also evidence that the spawning season for both Blueback Herring and Alewife is shifting sooner so surveys may need to start sooner to capture spawning fishes, especially in warm winters (Lombardo et al. 2020).

Trends through time

With a moratorium established in 2012, 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 born as ichthyoplankton, we were hopeful for a strong return in 2018. This has indeed materialized for Alewife, which has continued this three-year cycle trend into 2021. This trend is especially apparent in Accotink Creek, with the highest CPUE ever recorded, and while the 2021 numbers were lower in Pohick Creek, they are still the third highest behind 2015 and 2018. Now in 2022, we have seen River Herring numbers decrease in Accotink Creek, similar to the low years of this 3-year cycle. It will be interesting to see if this trend appears again in 2024. In Pohick creek, numbers of Blueback and Alewife were similar to those seen in 2019 and 2021, continuing a consistent spawner trend in this Creek. Unfortunately, Blueback Herring numbers were low again in 2022, and it appears that coastwide populations are doing poorly (personal communication with Virginia Alosa Taskforce). Although the numbers of Blueback were diminished, they are still higher than what was collected a decade ago, indicating at least some improvement perhaps as a result of the moratorium.

Through meetings with the Atlantic Coast River Herring Collaborative Forum (https://www.fisheries.noaa.gov/new-england-mid-atlantic/habitat-conservation/atlantic-coast-river-herring-collaborative-forum) it has become clear that not all tributaries of the Chesapeake Bay, have seen increased abundances as we are seeing here; some surveyors even reported declines (Nelson, 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. Thus, while the habitat in the Gunston Cove watershed can support large spawning populations now that reduced fishing pressure may allow more adults to return to their natal streams, additional stressors could play a role in the variable success of the moratoria. For example, 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). Interestingly, it appears that the River Herring of the Gunston Cove watershed may not be as anadromous as originally thought (Nelson pers. Observation), with many individuals remaining in brackish water throughout life. We have written a proposal to NOAA to investigate this trend and hope to incorporate telemetry and otolith chemistry work into future studies.

Table 4. The CPUE of four Clupeid species (Blueback Herring, Hickory Shad, Alewife, and Gizzard Shad) that occur in this area captured with block net during the spawning season.

	Accotink				**Pohick**			
Year	**Blueback**	**Hickory**	**Alewife**	**Gizzard**	**Blueback**	**Hickory**	**Alewife**	**Gizzard**
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
2021	1.0	0.2	61.3	3.2	3.7	3.0	21.2	0.0
2022	0.1	0.0	4.6	1.9	4.6	25.9	17.3	1.4

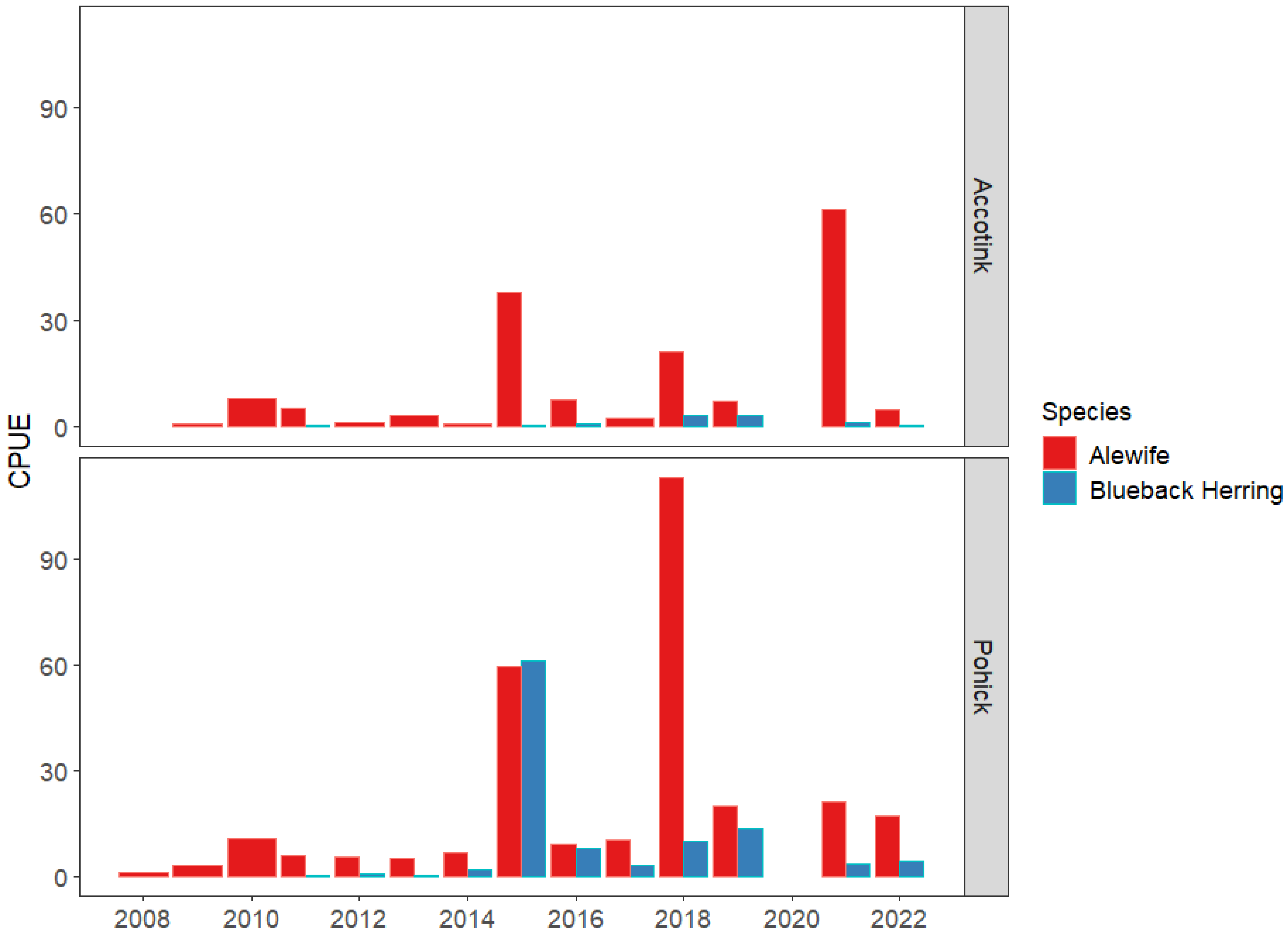

Figure 4. The CPUE (number of individuals per net sample) of *Alosa pseudoharengus* and *A. aestivalis* collected with the block net in each year.   Text

Literature Cited

Bethoney, N. D., K. D. E. Stokesbury, B. P. Schondelmeier, W. S. Hoffman, and M. P. Armstrong. 2014. Characterization of River Herring Bycatch in the Northwest Atlantic Midwater Trawl Fisheries. North American Journal of Fisheries Management 34(4):828-838.

Cummins, J.D. 2005. The Potomac River American Shad restoration project. 2004 Summary Report. Interstate Commission on the Potomac River Basin Report No. 05-2. 6 + 3 p.

Fay, C. W., R. J. Neves, and G. B. Pardue. 1983. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (mid-Atlantic). U.S. Fish and Wildlife Service, Blacksburg, VA.

Jones, P. W., F. D. Martin, and J. D. Hardy, Jr. 1978. Development of fishes of the Mid-Atlantic Bight: an atlas of egg, larval, and juvenile stages, volume 1. Acipenseridae through

Ictaluridae. U.S. Fish and Wildlife Service, FWS/OBS-78/12.

Kissil, G. W. 1974. Spawning of the Anadromous Alewife, *Alosa pseudoharengus*, in Bride Lake, Connecticut. Transactions of the American Fisheries Society 103:312–317.

Lake, T.R. and Schmidt. 1998. The relationship between fecundity of an Alewife (Alosa pseudoharengus) spawning population and egg productivity in Quassaic Creek, a Hudson River tributary (HRM 60) in Orange County, New York. Section II: 26 pp. In J.R. Waldman and W.C. Nieder (Eds). Final Reports of the Tibor T. Polgar Fellowship Program, 1997, Hudson River Foundation, NY.

Lippson, A. J., M. S. Haire, A. F. Holland, F. Jacobs, J. Jensen, R. L. Moran-Johnson, T. T. Polgar, and W. A. Richkus. 1979. Environmental atlas of the Potomac Estuary. Environmental Center, Martin Marietta Corp. 280 p.

Lippson, A. J., and R. L. Moran. 1974. Manual for the identification of early developmental stages of fishes of the Potomac River estuary. Maryland Department of Natural Resources, Baltimore.

Loesch, J. G., and W. A. Lund JR. 1977. A Contribution to the Life History of the Blueback Herring, *Alosa aestivalis*. Transactions of the American Fisheries Society 106:583–589.

Lombardo, S. M., J. A. Buckel, E. F. Hain, E. H. Griffith, and H. White. 2020. Evidence for temperature-dependent shifts in spawning times of anadromous alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*). Canadian Journal of Fisheries and Aquatic Sciences 77. NRC Research Press: 741–751. https://doi.org/10.1139/cjfas-2019-0140.

Massmann, W.H. 1961. A Potomac River shad fishery, 1814 – 1824. Chesapeake Sci. 2 (1-2): 76-81.

NOAA (Department of Commerce). 2006. Endangered and Threatened Species; Revision of Species of Concern List, Candidate Species Definition, and Candidate Species List. Federal Register, Vol. 71, No. 200, Tuesday, October 17, 2006, pp. 61022-61025.

Smith, H.M., and B.A.Bean . 1899. List of fishes known to inhabit the waters of the District of Columbia and vicinity. U.S. Fish Commission Bulletin 18:179-187.

Walsh H.J., L.R Settle, and D.S. Peters. 2005. Early life history of Blueback Herring and Alewife in the lower Roanoke River, North Carolina. Transactions of the American Fisheries Society 134:910-926.