2024 Water Quality Monitoring Program for Tidal Creeks in Calvert County, Maryland

Prepared for the Calvert County Board of County Commissioners

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Acknowledgements

We extend our gratitude to the following individuals and groups for their role in supporting the 2024 Quality Monitoring Program for tidal creeks in Calvert County, Maryland.

Executive Summary

Our monitoring work is divided between measurements in the Mill Creek system that have been ongoing since 1987 and efforts begun in 2009 to document water quality conditions in Calvert County tidal creeks. Below, we offer an executive summary for each of these components. Both precipitation and river discharge influence tidal water quality and are described below as they apply to both sampling programs.

Precipitation and River Flow/Discharge: Precipitation and river discharge patterns exert substantial influence on water quality conditions in many estuaries, including those considered in this monitoring program, because they help deliver sediments and nutrients from land to tidal waters.

Precipitation: The March through September 2024 average precipitation of 0.06 inches per day is lower than the long-term year average (Fig 3.1 A). The 2024 peak precipitation month was January with 5.33 inches cumulative precipitation averaging 0.17 inches per day. March was also fairly wet with 5.15 inches total with an average of 0.17 inches per day. October was the driest month with 0.01 inches of total rainfall with 0.0003 inches per day. In 2024, Calvert County experienced abnormally dry to severe drought conditions from early June through the end of the year. It is important to note that drought classification is based on multiple variables including precipitation.

River Discharge: The Patuxent River January-September 2024 mean flow was 396 cubic feet per second or cfs (measured at Bowie, MD), which was lower than the 38-year average of 410 cfs. Discharge rates in 2024 were highest in January and April.

MILL CREEK SUB-ESTUARY MONITORING PROGRAM

Yearly Monitoring Measurements:
Water column temperature, salinity, dissolved oxygen, chlorophyll-*a* concentrations, and clarity were measured at 10 fixed stations on 9 cruises during the spring and summer of 2024.

This report examines the patterns of Patuxent River flow, local precipitation, chlorophyll-*a* concentrations, and water column stratification in concert with long-term trends of bottom water dissolved oxygen concentration, algal blooms, and the absence or presence of sea nettles. Stratification is a measure of how strongly the water-column is mixed. When stratification is high, there is strong layering of fresher water on top of saltier water, which can restrict the amount of atmospheric oxygen that gets mixed into deeper water. We have also included the 2024 MDE fecal coliform data from this area and data from the Maryland Department of Health and Mental Hygiene and Calvert County Health department concerning water related infections.

Temperature: Both bottom and surface water temperatures increased during the summer, from a range of 19-23 ºC measured during the May 21st cruise to a range of 28-30 ºC recorded during the July 9th cruise. Surface water temperatures were typically higher than bottom temperatures, due to solar heating, and all stations had comparable

temperatures (within ~4 degrees Celsius). Surface and bottom temperatures were similar between stations over the sampling season.

Salinity: For most stations, salinity increased over the months of May, June, and July and were similar with one another for the rest of the sampling season. Bottom salinities were slightly greater than or equal to surface salinities.

Water Column Stratification: Stratification strength in the 2024 season was generally less than or equal to a difference of 1.5 sigma-t units between surface and bottom water, which is indicative of vertically well-mixed water. However, in May there were 2 instances of higher stratification with differences greater than 1.5 sigma-t units. By comparison, 4 instances occurred in 2023.

Dissolved Oxygen: Dissolved oxygen concentrations below 2.0 mg L^{-1} are considered hypoxic and are stressful to organisms. Bottom water dissolved oxygen concentrations were measured below 2.0 mg L^{-1} on five occasions in 2024 (6% of all surface and bottom water samples). This is a slightly higher occurrence than documented in 2023 but much lower than 2017 to 2021 where hypoxic conditions occurred 13-28% of the time. Bottom water dissolved oxygen saturation levels less than 50% saturation were observed 22% of the time (20 out of 90 bottom water observations). By comparison, in previous years saturation levels less than 50% were observed over 30% of the time, with the exception 2012 (observed 16% of the time).

Water Column Chlorophyll-a: Concentrations of active chlorophyll-*a* serve as a measure of the size of the algal populations in the water column. Average active surface chlorophyll-*a* levels for all stations were 14.19 μg L^{-1} in 2024, which is lower than the long-term mean (18.43 μg L^{-1}) of the five representative stations. A total of 13 surface samples indicated bloom levels in 2024, which we consider to be at concentrations greater than 20 μg L^{-1}.

Water Column Clarity: Water column clarity and light penetration are important factors contributing to the growth of submerged aquatic vegetation (SAV). SAV not only provides food, oxygen, nursery areas and shelter for Bay animals, but can trap sediment and nutrients, and slow erosion, thus further clearing the water.

The Mill Creek sub estuary is located in the mesohaline portion (salinity 5.0 to 18.0) of the Bay. At each station we measured light attenuation coefficients which quantifies how deep light penetrates in the water column. These coefficients were then used to calculate the depth where minimum light requirements (15% of surface light) were met for the growth of submerged aquatic vegetation. These values ranged from 0.66 to 2.38 meters during 2024. This is shallower than the average water depth, thus sufficient light for SAV growth was not generally present at the sediment during the 2024 sampling period for most stations.

Shellfish and Swimming Safety Review: We reviewed 2007-2024 MDE fecal coliform data for this drainage basin (Table 4.9). Quality standards for shellfish harvesting require fecal coliform concentrations less than 49 MPN (Most Probable Numbers) per 100

milliliters (mL) of water. In 2024, the highest value recorded (93 MPN/100 mL) occurred in October at Station 09-04-109A and was the only instance that exceeded the quality standard. Although the bacteria standards are being met most of the time, MDE will keep this area closed to shellfish harvesting due to oyster sanctuary status, shoreline activities, and the intensity of boating activities that increase the potential for overboard discharge of untreated sewage. The U.S. EPA regulatory concentration for closure of swimming areas is greater than 100 MPN fecal coliforms per 100 mL.

Calvert County Health Department provided information related to non-Cholera vibrio infections for Calvert County where cases remained low with no confirmed cases and only one probable case reported in 2024. Maryland Department of Health reported 37 confirmed cases and 125 probable cases in the state of Maryland. Note that the state totals were not yet finalized at the time of report submission but are expected to be similar to the totals reported here.

Long-Term Patterns in the Mill Creek System:
A subset of five representative stations (stations 2, 6, 7, 9 and 15) were used to investigate long-term trends in the Mill Creek System from 1987 to 2024. We define Mill Creek as the complex of tidal creeks north of Solomons Island including Back Creek, St. John Creek, and Mill Creek.

Dissolved Oxygen: The average bottom-water dissolved oxygen concentration in 2024 of 5.0 mg L^{-1} was higher than the long-term annual average (4.35 mg L^{-1}). A possible decline in bottom water dissolved concentrations over the long-term is suggested in the time series which may be related to increasing water temperature at the five sites. Even though truly anoxic conditions (dissolved oxygen concentrations of zero milligrams per liter) have never been observed, hypoxic conditions (less than 2.0 mg L^{-1}) are observed frequently enough to continue monitoring these trends. The Mill Creek system continues to experience periods of hypoxia that may impair habitat suitability for some organisms.

Chlorophyll-a: The surface mean active chlorophyll-*a* concentration of the five stations used for inter-annual analysis increased from an average of 14.49 µg L^{-1} in 2023 to 16.27 µg L^{-1} in 2024. This yearly average is lower than the 1987-2024 long-term average concentration of 18.43 µg L^{-1}.

Algal Blooms: Eleven of the 13 surface water algal blooms recorded in 2024 were observed at the 5 inter-annual comparison stations. A bloom is defined here as chlorophyll-*a* concentration greater than 20 µg L^{-1}. The annual average for the 5 representative stations is 11.6 blooms per year.

CALVERT COUNTY TIDAL TRIBUTARIES MONITORING PROGRAM

Yearly Monitoring Measurements
The 2024 Calvert County creek monitoring program included stations in Patuxent River creeks and Western Shore Chesapeake Bay creeks. The lower Patuxent River creeks (Hellen's Creek, St. Leonard Creek, Island Creek, and Hungerford Creek), the upper Patuxent River creeks (Battle Creek, Hunting Creek, and Hall Creek), the Western Shore

Chesapeake Bay creeks (Fishing Creek, Plum Point Creek, Flag Harbor, and Parkers Creek) were sampled in June, July, and August. A total of 32 stations were sampled in these creek systems. Hypoxic conditions were recorded on 9 occasions in 2024 with dissolved oxygen concentrations < 2 mg L^{-1}. Six of these instances occurred in the Lower Patuxent on St. Leonard Creek. The Upper Patuxent creeks had one instance of hypoxia at Battle Creek, and two instances were documented at Parkers Creek on the Western Shore. Algal blooms were common occurrences in all of the Calvert County creeks.

Tidal Creek Trends
Although improvement in a single water quality parameter is indicated at some sites, the overall finding of the trend analysis is that the majority of CBL and CPB sites are not demonstrating significant change over the past 12 years.

Summary and Conclusions

- Monitoring of Mill Creek estuarine system has been conducted since 1987 (data was not collected in 1989) providing a 38-year record of water quality conditions in the county. In addition, three creeks in the lower Patuxent have been monitored for sixteen years (2009-2024), one creek in the lower Patuxent has been monitored for thirteen years (2012-2024), three upper Patuxent creeks have been monitored for fifteen years (2010-2024), three Western Shore creeks have been monitored for fourteen years (2011-2024), and Parkers Creek has been monitored for twelve years (2013-2024).

- In terms of bottom water oxygen and chlorophyll-*a* concentrations, overall water quality of the Mill Creek system has been above-average for the past 2 years and surface chlorophyll levels have generally been declining since 2019.

- Monitoring of Calvert County tributaries continues to build our database for detecting change and response to watershed based restoration efforts. The prevalence of hypoxia in the lower Patuxent creeks and the widespread algal blooms across all sampled tributary sites suggests there is room for improvements to local water quality.

Recommendations

- Continue to monitor the Mill Creek sub-estuarine system so that both negative and positive trends in water quality can be clearly documented and can be used as a measure of the effectiveness of the Bay Restoration Fund work in this watershed. While previous reports have identified long-term degradation in this system, the most recent years have shown modest improvements in water quality.

- Continue to gather basic data in the Patuxent River and Chesapeake Bay tributaries of Calvert County. We recommend continued monitoring in each area to capture differences between years associated with local climate variability, with implementation of Best Management Practices, and to identify hot spots for water quality change. For example, St. Leonard Creek has some of the lowest oxygen of all creeks sampled, and Parkers creek has increasing chlorophyll-*a*.

- Continue to support planning and eventual implementation of sewer upgrades, BMPs, installation of enhanced nutrient removal (ENR) septic systems, riparian and other vegetative buffer zones, and encourage the use of pump-out facilities by boaters within the Mill Creek system.

- Continue to interpret conditions in the Calvert Creeks within the context of adjacent Patuxent River conditions, e.g. CBL Pier and along the estuary.

- Collaborate with CBL scientists who are working with the Chesapeake Bay Program water quality modeling team to develop a new and improved assessment model for the Patuxent estuary.

- The authors of this report are here to support Calvert County in Phase III of Maryland's Watershed Implementation Plan and any other relevant efforts to evaluate and ameliorate trends and causes of water quality changes in and around the county.

1   Introduction

As development adjacent to coastal and estuarine waters increases so does the risk that water quality of these areas will degrade. Water quality degradation is a concern not only in the large estuaries, such as Chesapeake Bay, but also in the smaller coves and tributary rivers adjoining these estuaries. In many cases these areas can be considered small estuaries or sub-estuaries. They are subjected to similar natural and anthropogenic influences as the larger estuaries. However, due to their smaller size and restricted flushing, the potential for dilution of pollutants is limited and the potential for algal blooms and general water quality deterioration is enhanced.

Located within the Dowell, Drum Point, Lusby, Olivet and Solomons portions of southern Calvert County, Maryland, the Mill Creek sub-estuarine system includes St. John's Creek, Mill Creek, Back Creek, The Narrows, and Solomons Harbor. Housing density and shoreline development are high surrounding the Mill Creek system, and the area continues to be increasingly popular with locals and visitors for the local culture and warm weather recreation.

In response to these management concerns, the Calvert County Board of County Commissioners provides the University of Maryland System, Center for Environmental Science, Chesapeake Biological Laboratory (UMCES CBL) with funding to monitor water quality conditions in the Mill Creek system. Past monitoring grants were awarded in 1987-1988 and 1990-2016. In 2017, the funding method changed, and we responded to an RFP and were awarded funding to continue monitoring. This reward was renewed for the 2022 monitoring year with support continuing through the 2024 monitoring year. We are encouraged to know that the county will continue monitoring over the next five years, 2025-2029.

The focal point of these studies was to measure the variables that best indicate stress to an estuarine system due to increased development and recreational activity. In the early years of this program, variables measured included particulate and dissolved nutrients, chlorophyll-*a*, fecal coliform concentrations, temperature, water column clarity, dissolved oxygen concentrations and salinity. Particulate and dissolved nutrients are no longer measured at these sites.

In addition to sampling the Mill Creek system, at the request of the Calvert County Commissioners, the 2009 water quality monitoring program expanded to include 10 new stations in 3 tributaries located in the lower Patuxent River estuary, all south of Broomes Island: 3 stations in Hellen's Creek, 4 stations in Saint Leonard Creek, and 3 stations in Island Creek. In 2010, the water quality monitoring program expanded again to include 9 new stations in 3 tributaries in the upper Patuxent River estuary: 3 stations in Battle Creek, 3 stations in Hunting Creek, and 3 stations in Hall Creek. Monitoring efforts increased once again in 2011 to include 8 new stations in 3 tributaries of the Chesapeake Bay western shore: 3 stations in Fishing Creek, 3 stations in Plum Point Creek, and 2 stations in Flag Harbor; and 2 stations in Hungerford Creek were added to the lower Patuxent Creeks sampling regime. The 2013 monitoring effort added Parkers Creek. All

stations in these additional tributaries were sampled 3 times yearly, once in June, July, and August.

At all stations (including the historical 10 stations in the Mill Creek sub-estuarine system), we tracked important water quality variables to determine changes in key indices between years. Surface and bottom water temperature, salinity, dissolved oxygen, and water clarity were measured. Water samples were collected, filtered, and analyzed for total and active chlorophyll-*a* concentration.

The effects and long-term trends of Patuxent River flow (otherwise referred to as discharge), precipitation, Mill Creek system chlorophyll-*a* concentrations, and the influence of water column stratification on bottom water dissolved oxygen levels were also examined.

2   Sampling Procedures

2.1   Station Locations and Sampling Frequency

Table 2.1, 2.2 & Figure 2.1, 2.2, 2.3

Water column data were collected at ten fixed stations in the Mill Creek system on nine different cruises that ran from May 21 to September 10. As in previous years, sampling stations were distributed throughout the Mill Creek system to ensure coverage of the area (Table 2.1, Figure 2.1). Four stations were positioned along Mill Creek (stations 3, 4, 6 and 7); two along St. Johns Creek (stations 8 and 9) and two located in Back Creek (stations 15 and 17). One station was located in The Narrows (station 11) and one at the mouth of the Mill Creek system (station 2). Data from stations 2 and 11 provide insight into the influence of the Patuxent River on water quality conditions in the Mill Creek system

Table 2.1 Location and average depth of the 2024 sampling sites in the Mill Creek system.

Station Number	Station Name	Average Depth (meters)	Latitude	Longitude
			(Decimal Degrees)	
2	Boat Shop	6.0	38.32182	-76.45015
3A	Bow Cove	5.1	38.32995	-76.45046
4	Pancake Point	4.6	38.33389	-76.44801
6	Coles Creek	2.7	38.33863	-76.43253
7	Ranch Club	1.7	38.34437	-76.42726
8	Hutchins Cove	3.1	38.33965	-76.44782
9	Lore's Creek	1.3	38.35033	-76.44876
11	Pilot Transfer Station	3.9	38.32369	-76.45905
15	Calvert Marina	4.1	38.33084	-76.45820
17A	Solomon's Landing	3.3	38.33722	-76.46079

Water column data were collected at 9 fixed stations in the upper Patuxent River creeks, 12 fixed stations in the lower Patuxent River creeks, and 11 fixed stations in the Western Shore Calvert County creeks on three monthly cruises in June, July, and August (Table 2.2, Figures. 2.2 and 2.3).

The Mill Creek system, lower Patuxent River, and Battle Creek sampling cruises were conducted aboard the R/V Pisces, a 25-ft CBL research vessel; the Aries, a 23-ft C-Hawk; and the Sourpuss, a 13-ft CBL Boston Whaler. The remaining upper Patuxent River and Western Shore cruises were conducted from the Sourpuss except for Parker's Creek which was sampled via canoe. Flag Harbor continued to be sampled off the dock. Sampling methods were similar to those of the other creeks in this monitoring program.
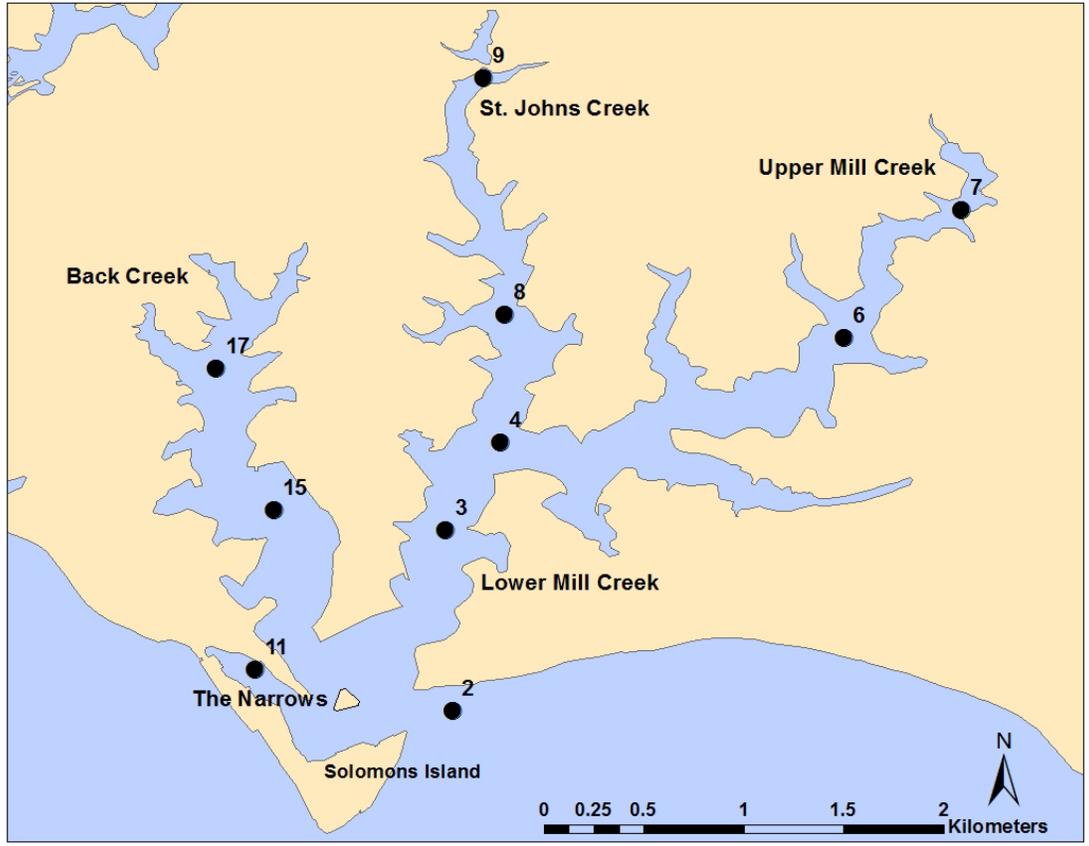
Figure 2.1 Map of the 2024 sampling sites in the Mill Creek system.

Table 2.2 Location and average depth of the 2024 sampling sites in the 4 lower Patuxent, 3 upper Patuxent River Creeks and 3 Western Shore Creeks.

Station	Average Depth meters	Latitude	Longitude
		Decimal Degrees	
Lower Patuxent			
SLC-1	5.2	38.3918	-76.4930
SLC-2	4.2	38.4075	-76.4868
SLC-3	3.2	38.4212	-76.4887
SLC-4	1.6	38.4357	-76.4840
HLN-1	3.8	38.3608	-76.4773
HLN-2	3.4	38.3665	-76.4750
HLN-3	1.3	38.3740	-76.4687
IC-1	3.1	38.4135	-76.5433
IC-2	2.5	38.4193	-76.5400
IC-3	1.1	38.4288	-76.5417
HNG-1	2	38.3531	-76.4656
HNG-2	1.1	38.3568	-76.4599
Upper Patuxent			
BAT-1	4.0	38.4521	-76.5992
BAT-2	2.7	38.4584	-76.5960
BAT-3	1.4	38.4734	-76.5981
HUN-1	2.3	38.5645	-76.6520
HUN-2	2.1	38.5684	-76.6339
HUN-3	1.9	38.5732	-76.6263
HAL-1	3.1	38.6886	-76.6899
HAL-2	3.2	38.6927	-76.6878
HAL-3	2.8	38.6909	-76.6802
Western Shore			
FSH-1	4.3	38.6905	-76.5379
FSH-2	1.9	38.6842	-76.5485
FSH-3	1.7	38.6785	-76.5580
PLM-1	1.0	38.6161	-76.5142
PLM-2	1.1	38.6194	-76.5149
PLM-3	0.7	38.6147	-76.5170
FLG-1	2.1	38.4636	-76.4730
FLG-2	1.6	38.4623	-76.4737
WR	1.6	38.5373	-76.5182
MC	0.9	38.5357	-76.5232
BS	1.0	38.5324	-76.5419

SLC = Saint Leonard's Creek   HUN = Hunting Creek   WR = Warrior's Rest (Parkers)
HLN = Hellen's Creek   HAL = Hall Creek   MC = Mini Creek (Parkers)
IC = Island Creek   FSH = Fishing Creek   BS = Bridge Spur (Parkers)
HNG = Hungerford Creek   PLM = Plum Point Creek
BAT = Battle Creek   FLG = Flag Harbor
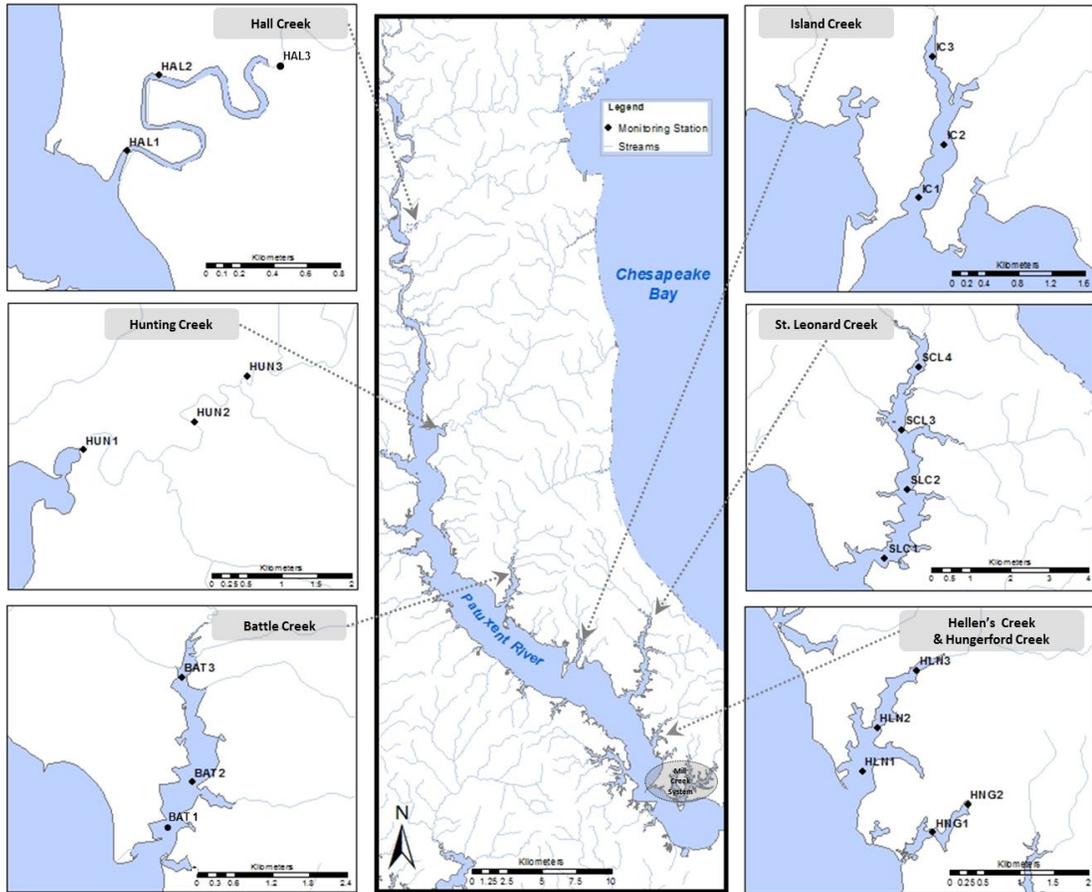
Figure 2.2. Maps of the 2024 sampling sites in Hall, Hunting, Battle, Island, St. Leonard, Hellen's, and Hungerford Creeks.
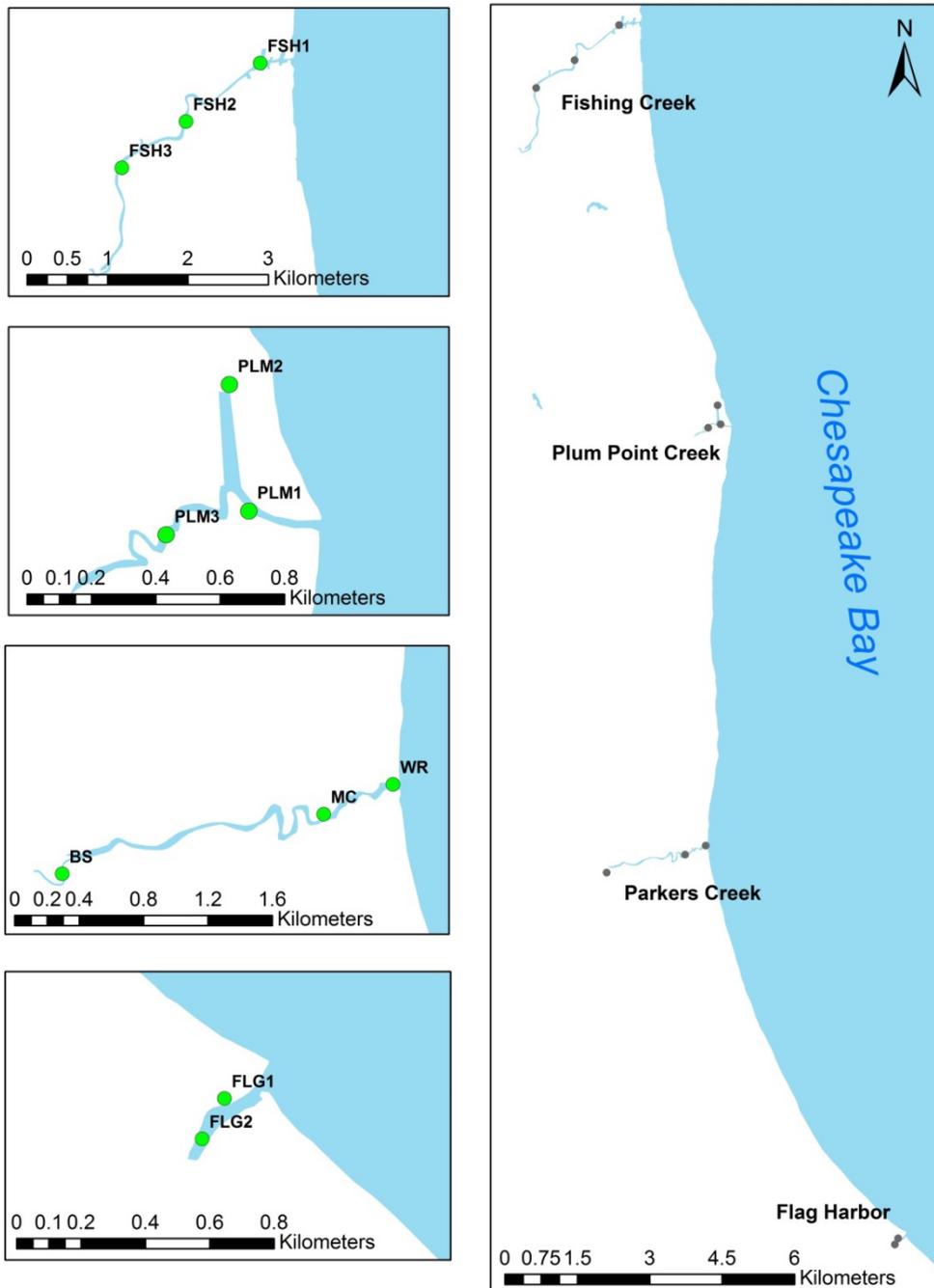
Figure 2.3 Maps of the 2024 sampling sites in Fishing Creek, Plum Point Creek, Parkers Creek, and Flag Harbor.

2.2 Water Quality Observations

Water column temperature, conductivity, salinity, and dissolved oxygen were measured at each station using a submersible water quality monitoring instrument (YSI model EXO2). Surface (0.5 meters) and bottom (0.5 meters above the sediment surface) measurements were taken at each site. Water clarity was measured using a Secchi disk. Beginning in 2015, light levels were collected with a LI-COR photosynthetically active radiation (PAR) sensor at the surface and at various water depths. Weather and sea-state conditions including air temperature, percent cloud cover, wind speed and direction, total water depth and wave height were recorded.

2.3 Chlorophyll-*a* Analyses

Samples of near-surface and near-bottom water were collected for chlorophyll-*a* analysis in separate, sample rinsed, 500mL dark polyethylene jugs using a small submersible pump (Rule model 1500). For each depth, aliquots of 10 to 200 mL were immediately filtered through a 0.7 μm glass fiber filter, wrapped in a labeled foil packet, then stored in a dark, iced cooler. After the cruise, the samples were immediately transported to the CBL Nutrient Analytical Services Laboratory (NASL) and frozen. Analyses of all samples were conducted by NASL using the standard operating protocols described in Keefe et al. (2004).

3 Precipitation Patterns and River Flow

3.1 Precipitation

Figure 3.1 A&B

To understand the water quality in the Mill Creek system and other Calvert County creeks it is critical to consider spring and summer precipitation. This section describes when and how materials enter the system from the surrounding land and from the Patuxent River. Conditions during 2024 are described and long-term trends are evaluated.

In general, the level of precipitation provides an index of the potential amount of nitrogen and phosphorus (as well as other materials), which could enter the Mill Creek system and tidal creeks as diffuse source run-off. While there is not a simple relationship between precipitation and diffuse source nutrient loading (Summers 1989), loading generally increases in proportion to precipitation. As a result, nutrient loads to the Mill Creek system and tidal creeks can be expected to be larger in wet versus dry years. The magnitude of river flow reflects the intensity of rainfall. Since river water is ultimately of terrestrial origin, it is responsible for the import of a significant amount of nutrients to the estuary (Kemp and Boynton 1992). This supply of nutrients can then generate spring and summer algal blooms, create increased water turbidity, and lead to low DO conditions.

The relationship between river flow and algal biomass has been documented in a number of estuaries (Nichols and Cloern 1985; Malone et al. 1988; Christian et al. 1991; Kemp and Boynton 1992). Typically, with increased river input, the amount of nutrients

imported to the system increases and therefore the potential for more intense algal blooms increases. Furthermore, decay of an algal bloom and its subsequent sinking to the bottom can stimulate the decay of the bloom material by bacteria, a process that consumes dissolved oxygen and decreases habitat quality for fish, seagrass, and other organisms. Work in the Chesapeake Bay (Wainger et al. 2016) has provided intriguing evidence that local water quality in sub-estuaries like the creeks monitored here are more likely to be influenced by surrounding smaller watersheds, rather than related to the larger scale trends in the mainstem. This was reinforced in recent years (2011-2020) as chlorophyll-*a* declined slightly in the nearby Patuxent River and mainstem of Chesapeake Bay, but increased in the Mill Creek system (Testa et al. 2018; Chesapeake Bay Program Trends tool; this report).

Average daily precipitation has been collected in the Mill Creek system (measured at a NOAA station located at CBL) for the period of March through September which includes the sampling dates of the Mill Creek system studies as well as springtime conditions that can impact nutrient inputs. This precipitation data also serves as an indicator of precipitation affecting other Calvert Creek tidal systems included in our monitoring program. Data can be downloaded from the following NOAA website when it is published:
https://www.ncdc.noaa.gov/cdoweb/datasets/GHCND/stations/GHCND:USC00188405/detail

Total 2024 rainfall was 23.14 inches. The March through September 2024 average precipitation of 0.06 inches per day is lower than the long-term annual average of 0.18 inches per day, which includes the months March to September to account for freshwater flow that influences early summer conditions (Fig 3.1 A). The 2024 peak precipitation month (Fig. 3.1 B) was January with a total of 5.33 inches (0.17 inches per day), followed by March with a total of 5.15 inches (0.17 inches per day,). October was the driest moth with a total of 0.01 total inches (0.0003 inches per day) followed by May with 0.32 inches of total rainfall (0.01 inches per day).

In 2024, Calvert County was experiencing abnormally dry to severe drought conditions from early June through the end of the year. It is important to note that drought classifications based on multiple variables including precipitation. For more information, please visit the following website:
https://www.drought.gov/states/maryland/county/calvert
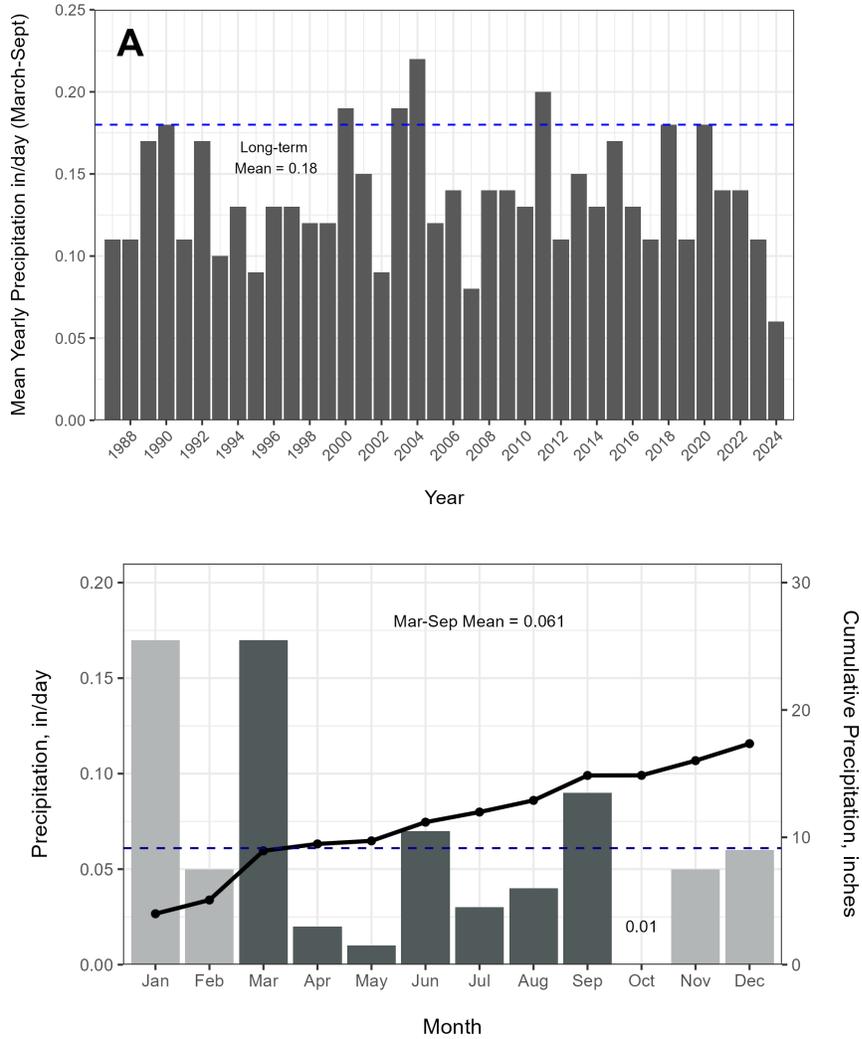
Figure 3.1 A&B Bar graphs showing (A) the mean daily seasonal precipitation (March through September) for 1987 to 2024 and (B) the mean daily precipitation by month (bars) in 2024 and cumulative precipitation (solid line). The darker bars indicated the months used for the seasonal precipitation in (A). The dashed horizontal lines indicate time-period averages.

3.2 River Flow

Figure 3.2 A&B

In the past, spring river discharge has been reported, but some years have had wetter summers, including 2018, and therefore we now report the January-September discharge from 1987-2024. Mean Patuxent River flow for each month was obtained from a gauge at station 01594440 Patuxent River at Bowie, MD, maintained by the United States Geological Survey (USGS). This river discharge affects tidal creeks located on the Patuxent side of the Calvert County peninsula, as well as the Mill Creek system and Solomons Harbor. The 25th and 75th percentile were determined from 1987-2024 to classify wet and dry years (Kimmel et al. 2009), which are highlighted in Figure 3.2A.
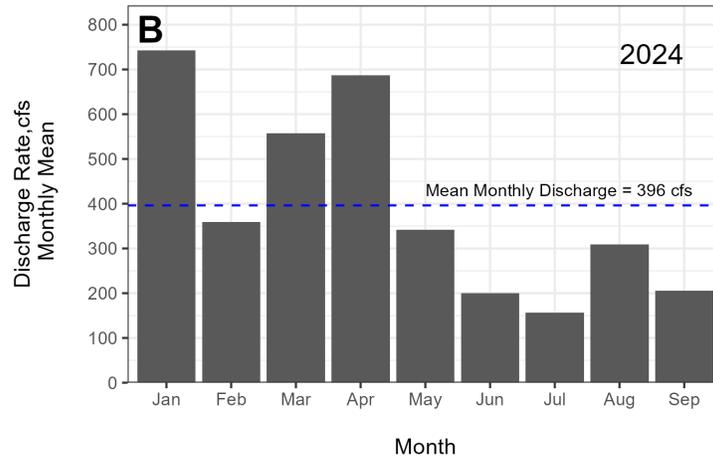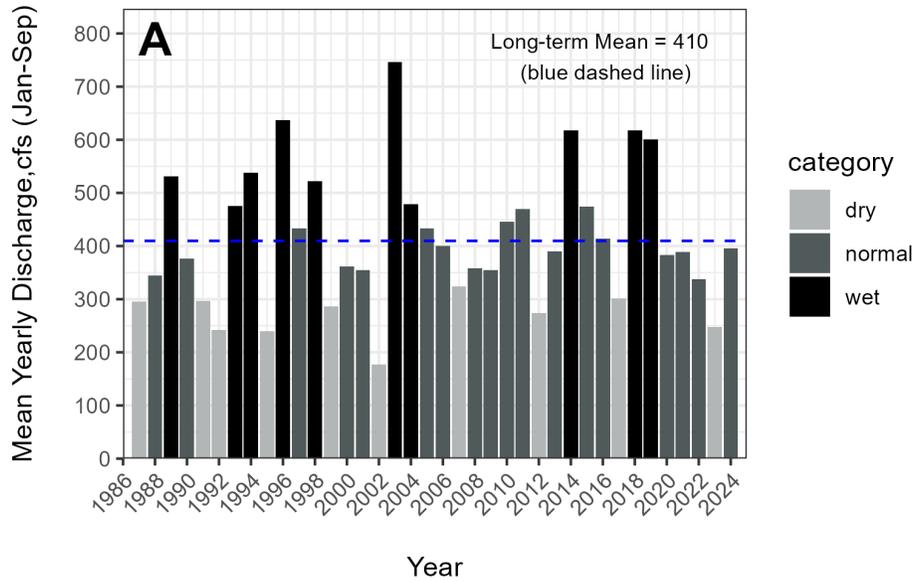
Figure 3.2 A&B Bar graphs showing (A) Patuxent River mean January through September flow 1987 to 2024, with darker bars representing wet years and lighter bars representing dry years and the (B) mean monthly flow (Jan-Sept) for 2024. Average flows during the history of the study are indicated in (A), while the monthly average for 2024 is indicated in (B).

The January-September 2024 mean monthly flow of 396 cubic feet per second (cfs), was lower than the 38-year mean (410 cfs) and was a normal year based on discharge rates (Fig. 3.2 A). Rates were highest in January and April (Fig. 3.2 B). Precipitation measured at CBL and river discharge measured at Bowie, MD do not always covary, reflecting the fact that precipitation that falls in the upper Patuxent watershed may be different from that in Calvert County. Precipitation and associated river discharge in the early part of the year (February to April) typically deliver the nutrients that support chlorophyll-*a* in both spring and summer, but large summer discharges can also stimulate blooms more immediately.

4   Mill Creek Sub-estuary: Water Quality Results and Discussion

All water quality data collected during the 2024 monitoring study in the Mill Creek sub-estuarine system are listed in Appendix I by station and date.

4.1   Temperature and Salinity

4.1.1   *Temperature*
Table 4.1, Figure 4.1 & 4.2

Surface water temperatures in 2024 ranged from 19.6 °C (station 2, May 21) to 30.1 °C (station 7, July 19) (Table 4.1). The bottom water temperature ranged from 19.0 °C (station 2, May 21) to 30.2 °C (station 9, July 19).

Both bottom and surface water temperatures increased from a range of 19.0 – 23.1 °C measured during the May 21th cruise to a range of 28.5-30.2 °C recorded during the July 19th cruise. An increase in minimum surface and bottom temperatures was seen in 2024. Maximum surface temperatures recorded were the same in 2023 and 2024 (30.1 degrees C) but maximum bottom temperatures increased from 29.6 in 2023 to 30.2 in 2024. Looking at these data across the 10 stations, we observed a typical seasonal pattern of warming temperatures. Temperatures were similar across all stations.

Note that 2020 sampling was delayed until June of that year due to the COVID pandemic, omitting the cooler conditions in May and therefore biasing the temperature minimum and maximum to higher values (Table 4.1, highlighted in red).

Table 4.1 Surface and bottom water temperature ranges (°C).

Year		2004	2005	2006	2007	2008	2009	2010	2011	2012
Surface	L	22.6	17.6	18.1	18.7	17.2	18.1	17.2	20.3	20.6
	H	29.9	31.2	29.5	28.3	29.1	32.0	30.6	31.7	30.0
Bottom	L	21.6	16.9	17.9	18.2	17.1	17.6	17.4	19.1	18.5
	H	29.2	29.6	29.5	28.3	29.1	30.3	30.2	31.3	29.9
Year		2013	2014	2015	2016	2017	2018	2019	2020	2021
Surface	L	17.0	21.2	22.4	16.6	19.2	20.8	21.7	23.1	18.9
	H	28.6	29.6	30.7	30.3	30.9	31.2	31.7	30.8	30.6
Bottom	L	16.9	17.9	19.2	16.1	18.6	20.0	19.2	22.6	18.8
	H	29.1	29.5	30.3	30.2	30.7	30.6	31.4	30.4	29.3
Year		2022	2023	2024						
Surface	L	19.0	18.6	19.6						
	H	31.4	30.1	30.1						
Bottom	L	16.4	18.7	19.0						
	H	31.2	29.6	30.2						
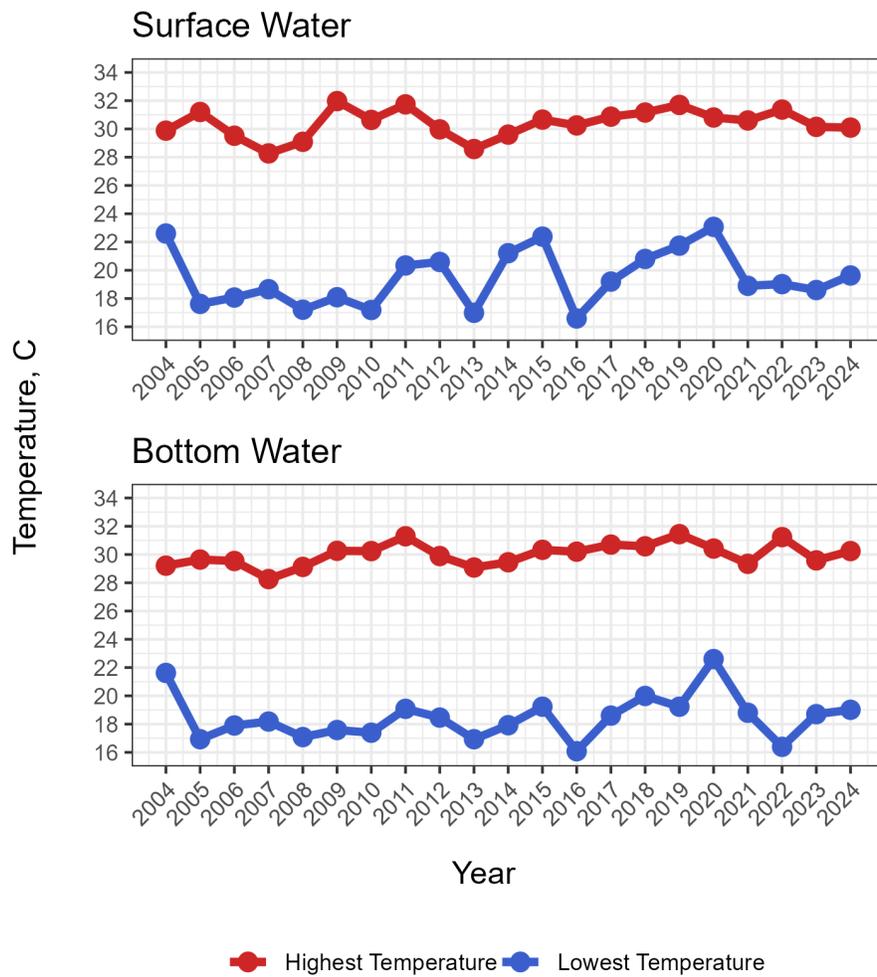
Figure 4.1 Historical surface and bottom water temperatures (°C), 2004-2024.
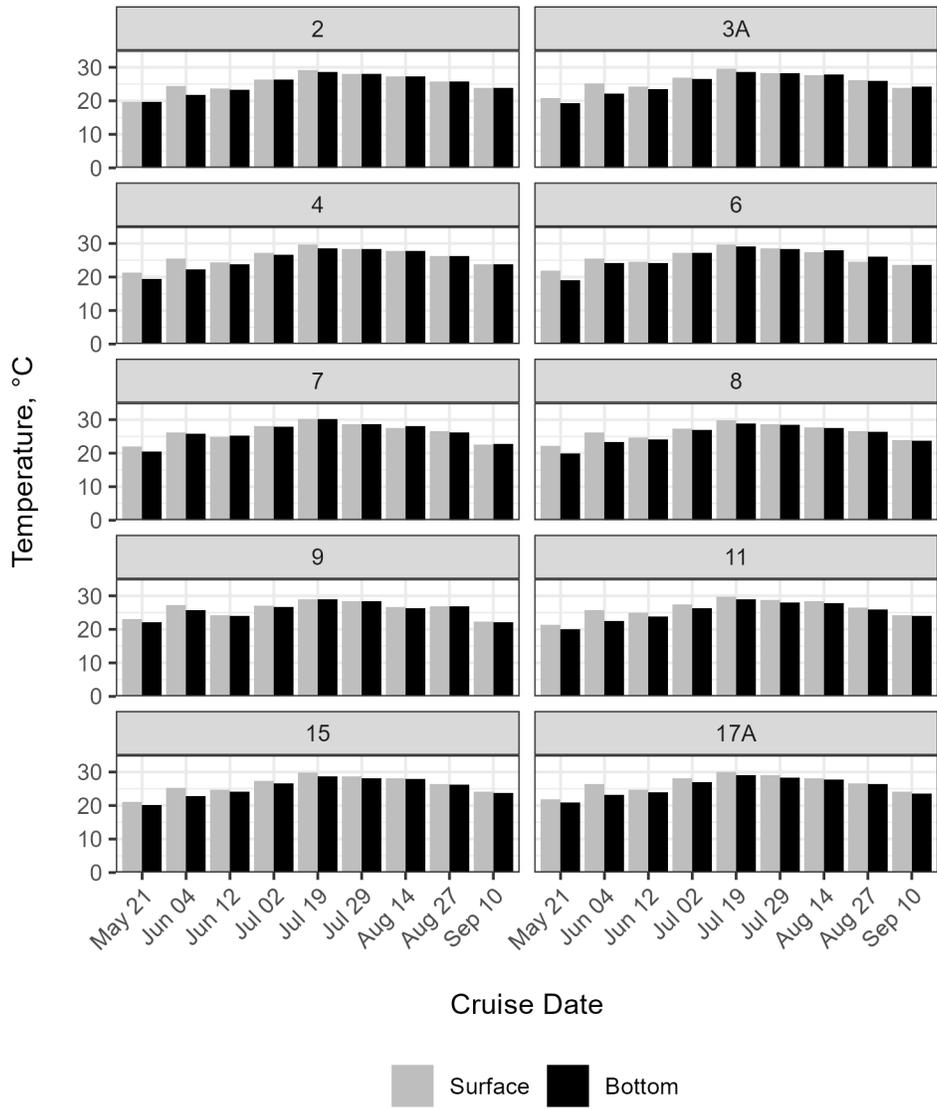
Figure 4.2 Bar graphs of surface and bottom water temperature measured at each station from May 21 through September 10, 2024.

4.1.2 *Salinity*

Table 4.2, Figure 4.3 & 4.4

The minimum and maximum salinity values for surface and bottom water in 2024 were lower than 2023 which may be related to the corresponding increase in discharge measured on the Patuxent River. The average difference between surface and bottom salinities was 0.25 psu. Surface water salinity ranged from 6.2 (station 7, May 21) to 11.7 (station 2, Sept 10). Bottom water salinity ranged from 7.8 (station 2, May 21) to 11.8 (station 11, Sept 10).

Table 4.2 Surface and bottom water salinity ranges in the Mill Creek System.

Year		2004	2005	2006	2007	2008	2009	2010	2011	2012
Surface	L	6.1	5.05	9.8	9.1	6.4	9.7	9.2	4.0	11.4
	H	11.9	14.7	14.9	15.2	14.0	14.2	17.2	13.3	15.1
Bottom	L	7.9	8.3	10.4	9.7	7.8	10.8	10.2	4.5	11.7
	H	12.4	14.8	15.3	15.9	14.3	14.4	17.5	13.5	15.5
Year		2013	2014	2015	2016	2017	2018	2019	2020	**2021**
Surface	L	7.5	6.7	8.9	6.7	4.7	3.5	2.3	8.0	9.4
	H	14.2	13.7	14.2	16.4	12.5	9.9	12.3	13.1	13.4
Bottom	L	8.8	7. 8	11.3	11.5	10.0	6.6	3.6	10.2	11.0
	H	14.4	13.8	14.2	16.4	13.3	10.9	12.5	13.7	13.7
Year		2022	2023	2024						
Surface	L	4.01	9.4	6.2						
	H	17.9	15.9	11.7						
Bottom	L	5.62	11.8	7.8						
	H	18.3	16.3	11.8						
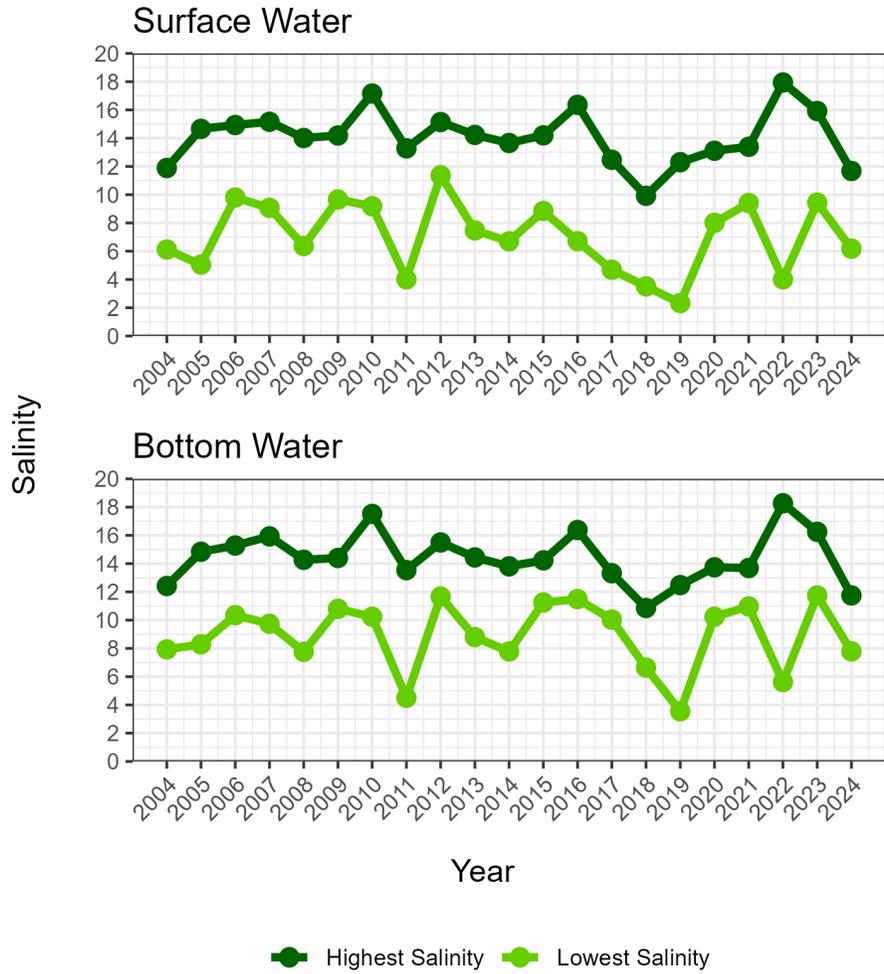
Figure 4.3 Historical surface and bottom water salinity in the Mill Creek System, 2004-2024.
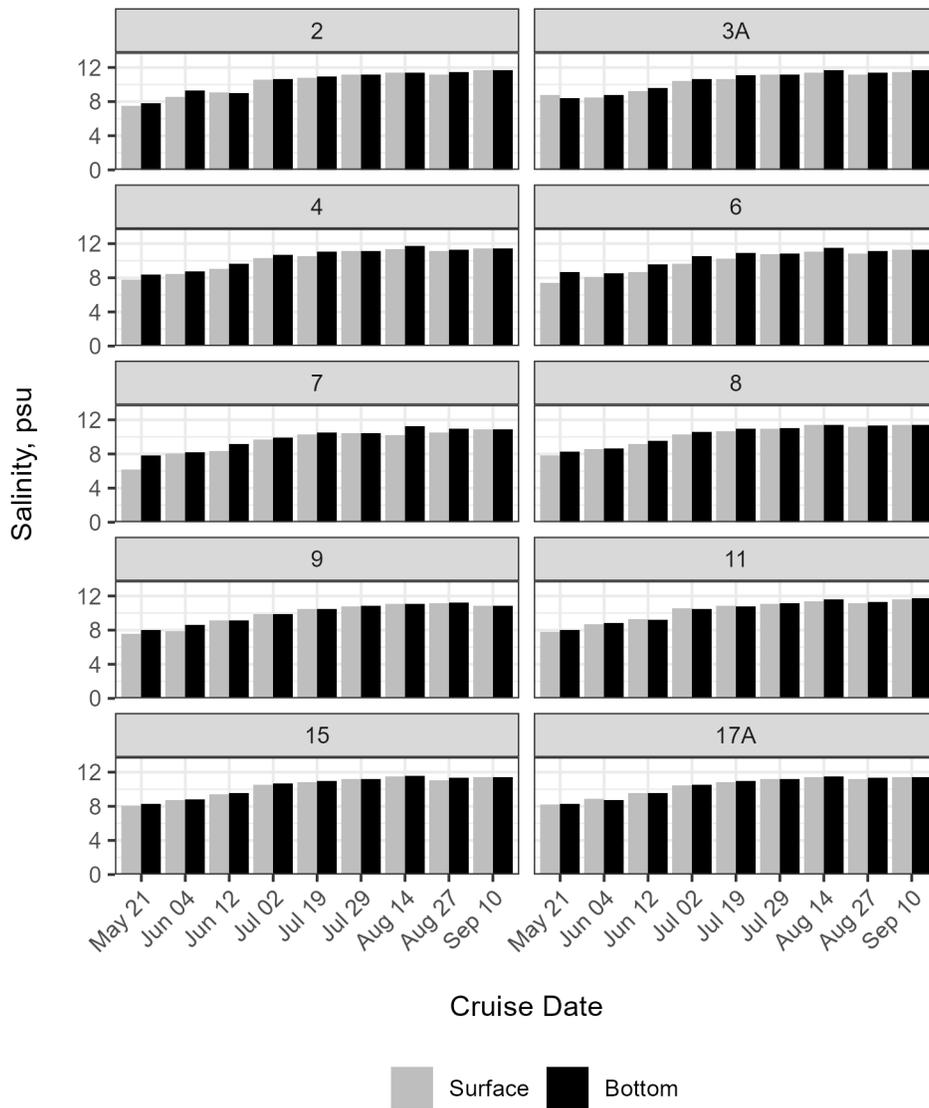
Figure 4.4 Bar graphs of surface and bottom water salinity values measured at each station in the Mill Creek System from May 21 through September 10, 2024.

4.1.3 *Stratification Strength*

Figure 4.5

Sigma-t (a measure of density computed using water temperature and salinity) of the surface and bottom waters was calculated for each station and sampling date. The difference between surface and bottom sigma-t values provides an indication of the stratification strength of the water column. Stratification in an estuary indicates the layering of water of differing densities, where strong layering can prevent oxygen delivery to bottom water. Density differences result from water of varying temperature and salinity conditions, where cold, high salinity waters are denser than fresh, warm waters. Waters stratify when density differences are not overwhelmed by other physical forces, like wind, tides, or currents.

Stratification strength in the 2024 season was generally less than a difference of 1.5 sigma-t units between surface and bottom water across all stations and sampling times, which is indicative of weak stratification strength. We documented higher stratification with differences greater than 1.5 sigma-t units twice in 2024 compared to 4 instances in 2023. Both instances were between 1.5 and 2.5 and occurred on May 21 at the Upper Mill Creek stations (6 and 7), which may correspond to a local rainfall event or to other factors such as tide stage. We are interested in stratification because it can create conditions where   a) bottom waters are not replenished with oxygen from mixing with the atmosphere and
b) phytoplankton in the surface waters can become nutrient limited when nitrogen and phosphorus recycled in sediments is not mixed upward to the surface.
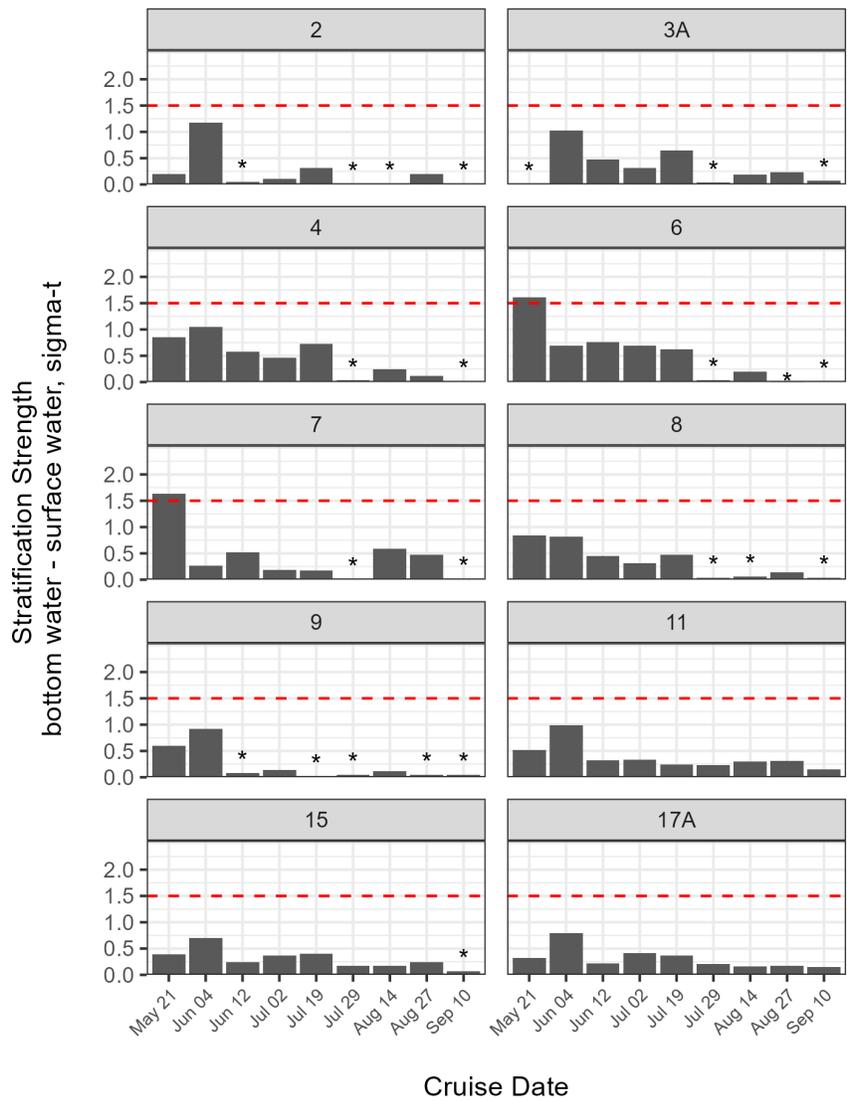
Figure 4.5 Bar graphs of water column stratification represented as the difference between surface and bottom water sigma-t values calculated for each Mill Creek station from May 21 through September 10, 2024. Stratification strength below 1.5 (dashed line) indicates well mixed water. *Indicates very small sigma-t values (<0.1).

4.2 Dissolved Oxygen

Table 4.3 & 4.4, Figure 4.6 & 4.7A

The dissolved oxygen concentration of surface waters in the Mill Creek complex ranged from 3.86 milligrams per liter (mg L^{-1}) (station 7, July 19) to 10.31 mg L^{-1} (station 11, May 21). Bottom water dissolved oxygen concentrations ranged from 0.41 mg L^{-1} (station 6, May 21) to 8.99 mg L^{-1} (station 2, May 21).

Table 4.3 Historical surface and bottom water oxygen concentration ranges (mg L^{-1}) in the Mill Creek System. SW= surface water. BW = bottom water.

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012
SW Min	0.79	1.86	2.10	2.12	2.77	3.04	2.81	1.86	2.81
SW Max	10.10	11.92	9.47	8.32	8.89	15.06	8.66	14.42	10.16
BW Min	0.18	0.30	1.18	0.88	0.98	0.31	2.10	0.26	1.90
BW Max	7.31	9.56	7.91	6.99	8.17	9.51	9.02	13.93	8.92
Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
SW Min	1.76	2.11	2.53	1.78	2.15	2.46	2.51	1.59	2.58
SW Max	8.92	11.13	8.85	8.50	9.54	10.42	8.95	8.41	11.15
BW Min	0.44	0.77	0.36	1.21	0.76	0.39	0.38	0.49	0.16
BW Max	8.77	10.05	9.11	7.70	9.00	8.59	7.56	7.28	9.90
Year	**2022**	**2023**	**2024**						
SW Min	2.07	2.70	3.86						
SW Max	11.47	12.25	10.31						
BW Min	0.52	0.28	0.41						
BW Max	9.08	10.51	8.99						

Five of the bottom water dissolved oxygen concentration measurements were below 2.0 mg L^{-1} during the 2024 study (see figure 4.7 A for historical comparisons). Levels below 2.0 mg L^{-1} are considered hypoxic and are very stressful to organisms. The percent of hypoxic readings during the drier years (e.g. 2012, 2007) have been typically low relative to the wetter years (e.g. 2005), but this has not always been the case in the last decade. The year 2018 was a wet year and saw a high amount of hypoxia, while 2017 was a drier year and saw high hypoxia percentages as well. Based on discharge, 2024 was a normal year and had relatively few incidences of hypoxia compared to most years over the time series. Note that the 2020 ranges of minimum surface water and maximum bottom water dissolved oxygen levels (Table 4.3, highlighted in red) appear to be biased lower due to the omission of the May sampling dates.

Table 4.4 Percent hypoxic readings in the bottom water (<2.0 mg L^{-1}) in the Mill Creek System.

2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
25%	24%	10%	11%	17%	13%	0%	21%	3%	10%
2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
10%	9%	6%	23%	28%	13%	16%	17%	21%	2%
2024									
6%									

True anoxic conditions (0.00 mg L^{-1} dissolved oxygen) have not been recorded on the sampling dates of any Mill Creek system cruise. It may be that only high frequency monitoring will record any short-term (less than 2 weeks in duration) anoxic events if they do occur as water column respiration processes that consume oxygen typically peak in the night and pre-dawn hours, which are outside of the time we sample.
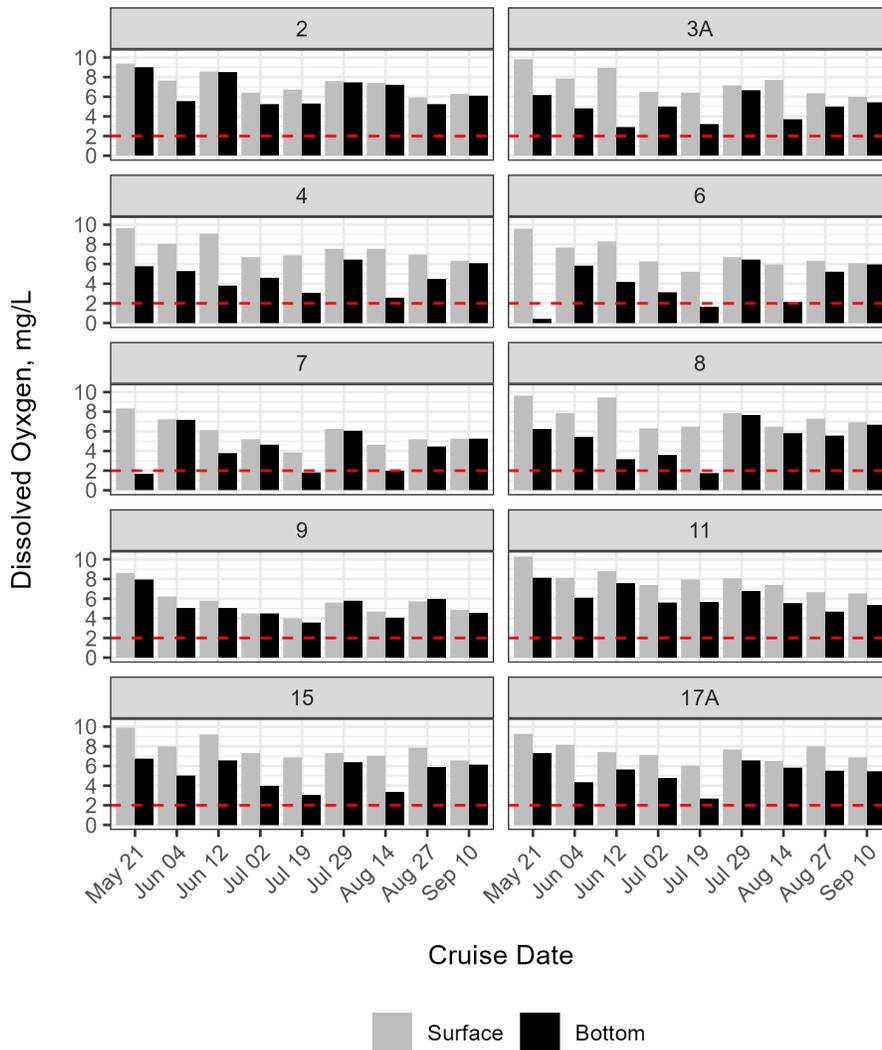
Figure 4.6 Bar graphs of surface and bottom water dissolved oxygen concentrations measured at each Mill Creek station from May 21 through September 10, 2024.

The data in Figure 4.6 show that some of the stations are more vulnerable to low dissolved oxygen than others. The instances of hypoxic conditions occurred in bottom water at stations 6 (Cole's Creek) and 7 (Ranch Club) on May 21 and July 19, and at station 8 on July 19.

4.2.1 *Dissolved Oxygen Saturation Levels*

Table 4.5 & Figure 4.7B

Oxygen from the air dissolves in the water column in proportion to water temperature and salinity. When oxygen dissolved in water is in equilibrium with that in air, the water is 100% saturated with dissolved oxygen. Oxygen is replenished in water by direct exchange with air at the surface and through the efforts of photosynthesizing phytoplankton in the water column releasing oxygen to the water. Respiration by organisms in the water and in the mud, as well as some chemical processes, consumes oxygen in the water, causing the oxygen content to fall below the 100% saturation level.

Bottom water dissolved oxygen saturation levels less than 50% saturation were observed 22% of the time (20 out of 90 observations) in 2024. The frequency of these lower saturation readings is similar to that seen in 2023, and is the lowest since 2012 when only 16% of bottom water readings were hypoxic. With the exception of these three years (2012, 2023, and 2024), hypoxic conditions have typically represented at least 30% of the bottom water oxygen readings each year since 2004.

Table 4.5 Percent bottom water dissolved oxygen saturation levels less than 50%, by year.

2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
50%	44%	36%	39%	54%	32%	31%	58%	16%	31%
2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
39%	39%	30%	57%	58%	42%	45%	59%	57%	26%
2024									
22%									
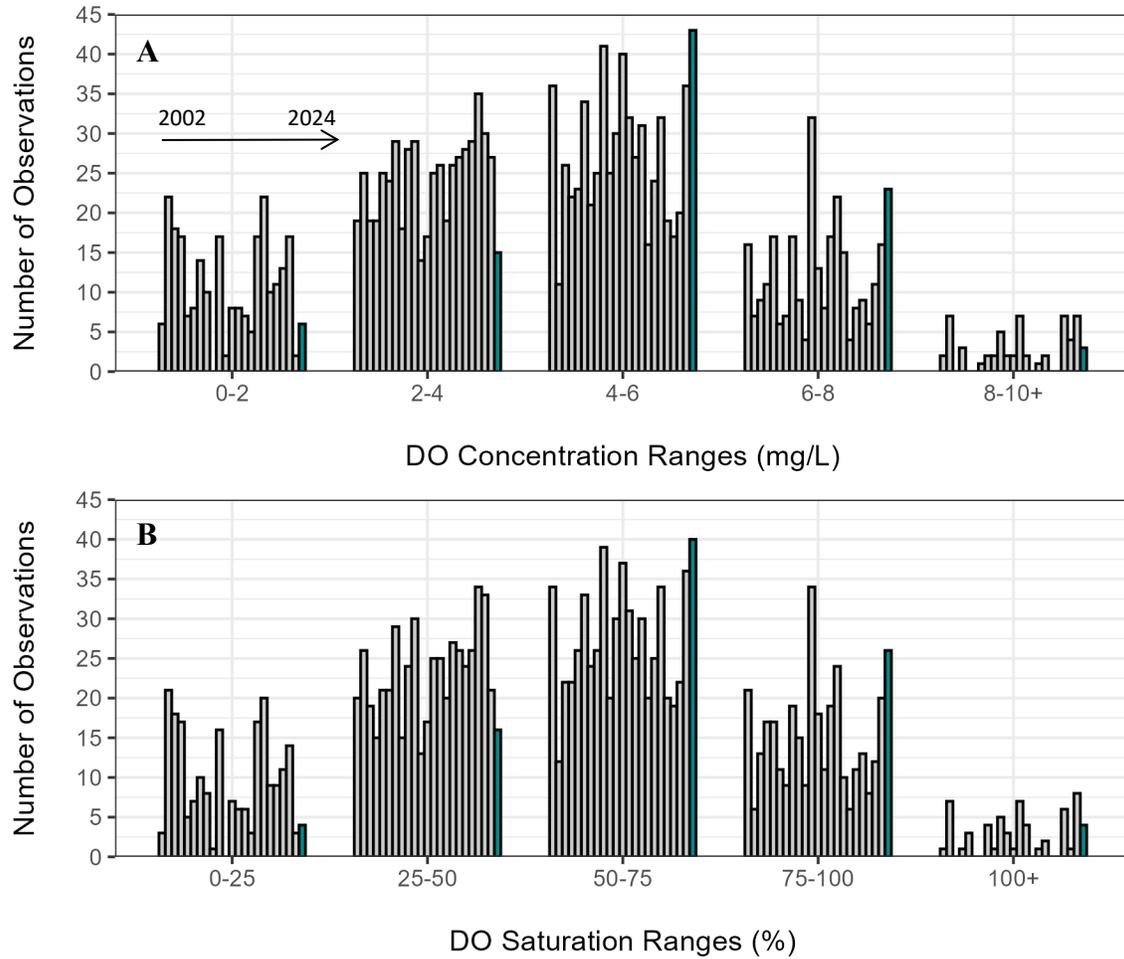
Figure 4.7 A & B Bar graphs comparing the distribution of bottom water dissolved oxygen (A) and bottom water percent oxygen saturation (B) observations, 2002-2024 from left to right each category. The green/dark bars represent 2024.

4.3   Active Chlorophyll-*a*

Table 4.6 & 4.7 & Figure 4.8

Active chlorophyll-*a* concentration serves as a measure of water-column algal community densities. Total chlorophyll-*a* measurements include phaeophytin, a chlorophyll degradation product. Active chlorophyll-*a* concentrations in surface waters ranged from 4.26 micrograms per liter ($\mu g\ L^{-1}$) (station 8, Aug 27) to 38.55 $\mu g\ L^{-1}$ (station 9, July 19) (Figure 4.8). Bottom water concentrations ranged from 4.53 $\mu g\ L^{-1}$ (station 3A, Aug 27) to 40.34 $\mu g\ L^{-1}$ (station 9, July 2).

Table 4.6   Historical surface and bottom active chlorophyll-*a* ($\mu g\ L^{-1}$) ranges in Mill Creek.

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012
Surface	5-88	4-225	5-57	4-64	5-91	4-78	3-72	6-207	8-33
Bottom	3-41	3-42	2-68	5-47	3-53	6-58	5-242	4-118	3-121
Year	2013	2014	2015	2016	2017	2018	2019	2020	2021
Surface	6-66	5-86	5-39	4-45	3-73	3-166	7-66	6-99	6-63
Bottom	5-56	6-108	6-55	6-91	7-37	2 -39	6-129	5-122	5-50
Year	2022	2023	2024						
Surface	4-52	5-32	4-39						
Bottom	4-322	4-41	5-40						

Concentrations greater than 20 $\mu g\ L^{-1}$ indicate the presence of an algal bloom (severe bloom concentrations in the Patuxent River have exceeded 300 $\mu g\ L^{-1}$). In 2024, stations 7 and 9 had relatively higher concentrations than other stations throughout the summer with multiple blooms. This is a pattern we have documented in recent years and it may be of note that dissolved oxygen levels were generally lower at these stations. In general, the other stations had lower chlorophyll levels but only stations 2 (Boat Shop) and 11 (Pilot Transfer Station) did not experience blooms in 2024. Average active chlorophyll concentrations were lower in the past few years (2021 to 2024) than in recent years (2018-2020) when averages were above the bloom level (Table 4.7).

Table 4.7   Average surface active chlorophyll-*a* ($\mu g\ L^{-1}$) concentrations in the Mill Creek System.

2004	2005	2006	2007	2008	2009	2010	2011	2012
18.93	14.24	14.68	19.97	15.63	15.59	17.51	29.25	14.25
2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
16.13	18.47	15.87	13.49	16.63	21.51	20.48	20.58	15.04
2022	**2023**	**2024**						
12.94	13.61	14.19						
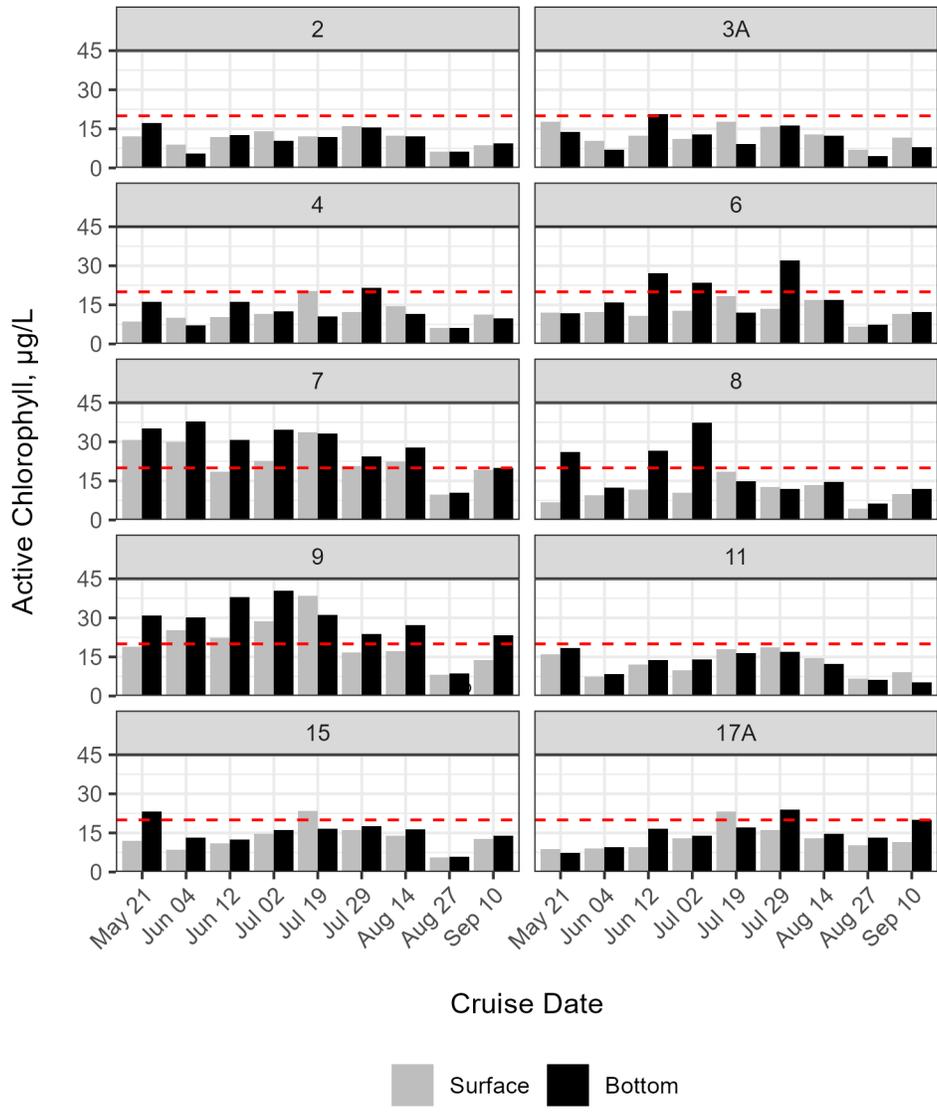
Figure 4.8 Bar graphs of surface and bottom water active chlorophyll-*a* values for each station in Mill Creek from May 21 through September 10, 2024. Values above 20 μg L^{-1} (dashed line) are considered blooms.

4.4 Water Column Clarity

4.4.1 *Secchi Disk Readings*

Table 4.8 & Figure 4.9

Water clarity was measured using a Secchi disk. The highest 2024 Secchi disk measurement (indicating the clearest water) was 1.8 meters measured at stations 4 (Pancake Point) and 8 (Hutchins Cove) on May 21st. The lowest measurements (0.5 m) occurred at station 7 (Ranch Club) on July 19th, and at station 9 (Lore's Creek) on July 2nd, 19th , 29th, and August 14th. Station 9 exhibited the lowest average readings (0.6 m) in 2024.

Minimum Secchi readings in 2024 were similar to those recorded in 2020-2023 although the maximum Secchi depth decreased from 2.1 m in 2023 to 1.8 m. Most stations experienced peak Secchi depths in May when live *Zannichellia*, an SAV species, was observed in St. Johns Creek and Mill Creek. By early June, most *Zannichellia* had disappeared or was decaying, which is consistent with the life cycle of this species. It is encouraging that a population of SAV can still recruit to this system, and if water clarity improves, perhaps summer SAV species could return to Mill Creek.

Table 4.8 Historical Secchi disk ranges (lowest to highest clarity) in the Mill Creek System.

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012
Secchi Range	0.5-2.0	0.2-2.0	0.4-1.7	0.4-1.8	0.3-2.2	0.3-2.0	0.4-2.1	0.2-1.5	0.4-1.8
Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Secchi Range	0.4-1.6	0.3-1.4	0.2-1.8	0.3- 2.0	0.3- 1.8	0.4-1.6	0.3-1.6	0.2-1.4	0.4-1.9
Year	**2022**	**2023**	**2024**						
Secchi Range	0.2-2.4	0.4-2.1	0.5-1.8						
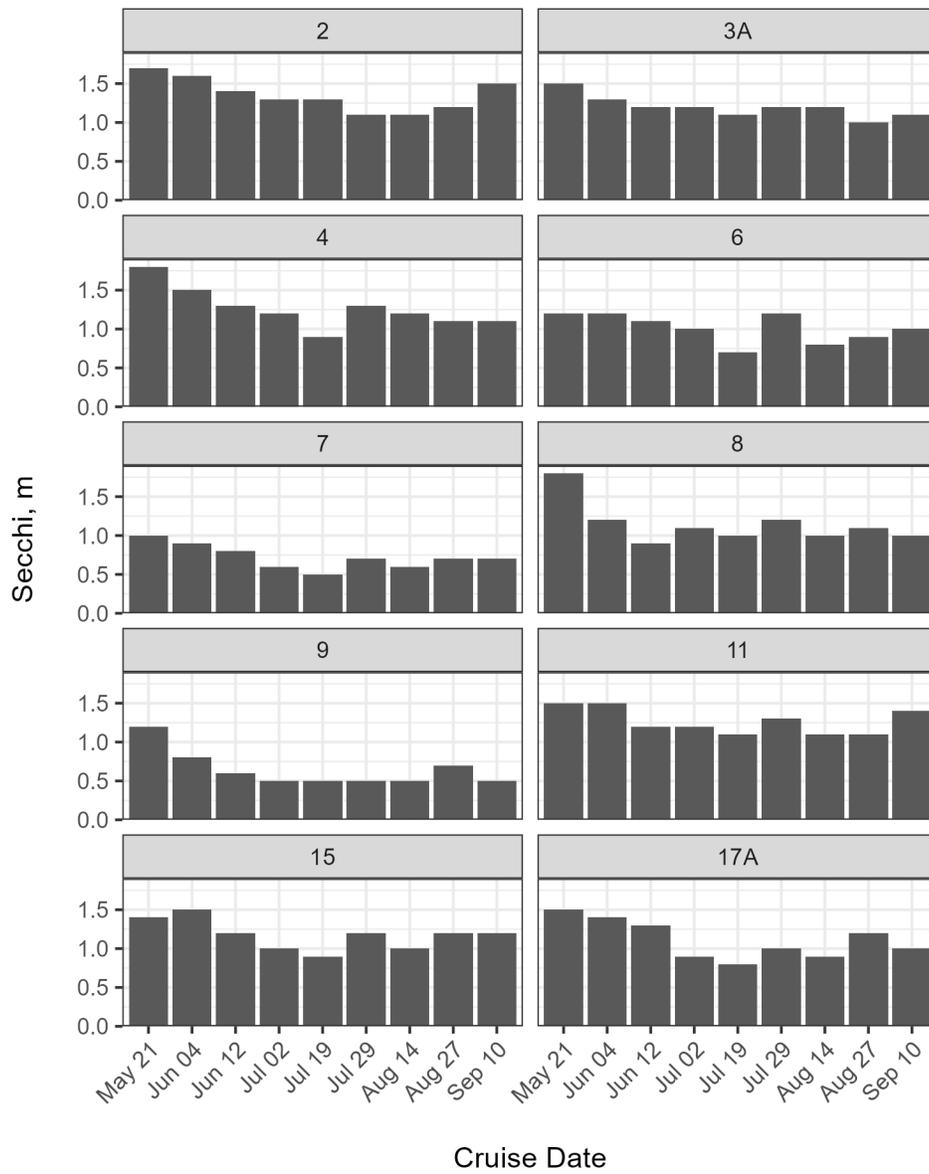
Figure 4.9 Bar graphs of water column Secchi disk measurements for each station in the Mill Creek System from May 21 throughout September 10, 2024.

4.4.2 *Light Penetration measured by light profiles (Kd)*
Figure 4.10

Water column clarity and light penetration are very important parameters contributing to the growth and habitat suitability for submerged aquatic vegetation (SAV). SAV not only provides food, oxygen, nursery areas and shelter for Bay animals, but can trap sediment and slow erosion, thus further clearing the water. In this way, SAV beds serve as "engineers" that establish better water quality in their vicinity to self-support their own growth.

Potential SAV habitat can be quantified by measuring the clarity of water and associated areas of the Bay bottom that have enough light to support SAV growth. We quantify water clarity by estimating a number that quantifies how fast light disappears when we lower a light sensor into the water column. This number is called the light attenuation coefficient, where low values represent clear water. The Mill Creek sub estuary is located in the mesohaline (salinity of 5.0 to 18.0) portion of the Bay. The goal in this area is to restore SAV to depths of one meter, requiring a light attenuation coefficient of ≤ 1.5 m^{-1} (Kemp et al. 2004).

This extinction or light attenuation coefficient (Kd) has been estimated based on the Secchi disk depth using the following equation: Kd = 1.43/Secchi disk depth (Keefe et al. 1976). For the past five years, Kd was also calculated from measurements of the light at various depths by finding the exponential fit to light vs. depth. This estimate of light penetration into the water-column is a more accurate representation of light available to SAV, as it is based on direct measurements of light availability in the water.

We can use these calculations of Kd to determine the depth that sufficient light penetrates for both algal growth (1% of surface light) and SAV growth (at 15% of surface light) (Kemp et al. 2004). Using the Kd values from the light profile data suggests that light penetration sufficient for algal growth existed at depth ranges from 1.4 meters (Station 9 on Aug 14) to 6.3 meters (Station 11 on May 21st), with a seasonal average depth to 1% light penetration of 3.1 meters.

Using the Kd values estimated with Secchi depth, the depth at which light penetration is sufficient for algal growth (the euphotic zone), ranged from a low of 1.6 meters (Station 7 on July 19th, and Station 9 on July 2, July 19, July 29, August 14th, and September 10th) to 5.8 meters (Stations 4 and 8 on May 21st). The seasonal average light attenuation allowed for 1% penetration to 3.19 meters. Regardless of method, light for algal growth was present on average throughout much of the water column on most sampling dates since the mean depth of the Mill Creek system was approximately 3.6 meters.

During the sampling season, the depth of 15% light penetration sufficient for SAV growth ranged from 0.66 meters to 2.38 meters with an average penetration of 2.38 meters with Kd estimated with Secchi disk depth. With the light profile calculations, these depths ranged from 0.58 to 2.58 meters with an average penetration of 1.29 meters. Light sufficient for SAV growth was not available for many of the deeper stations in the Mill Creek system, as found in previous years. This is consistent with our observations

of SAV growth which was generally seen at stations 7 and 9 where depths are less than 2 meters.
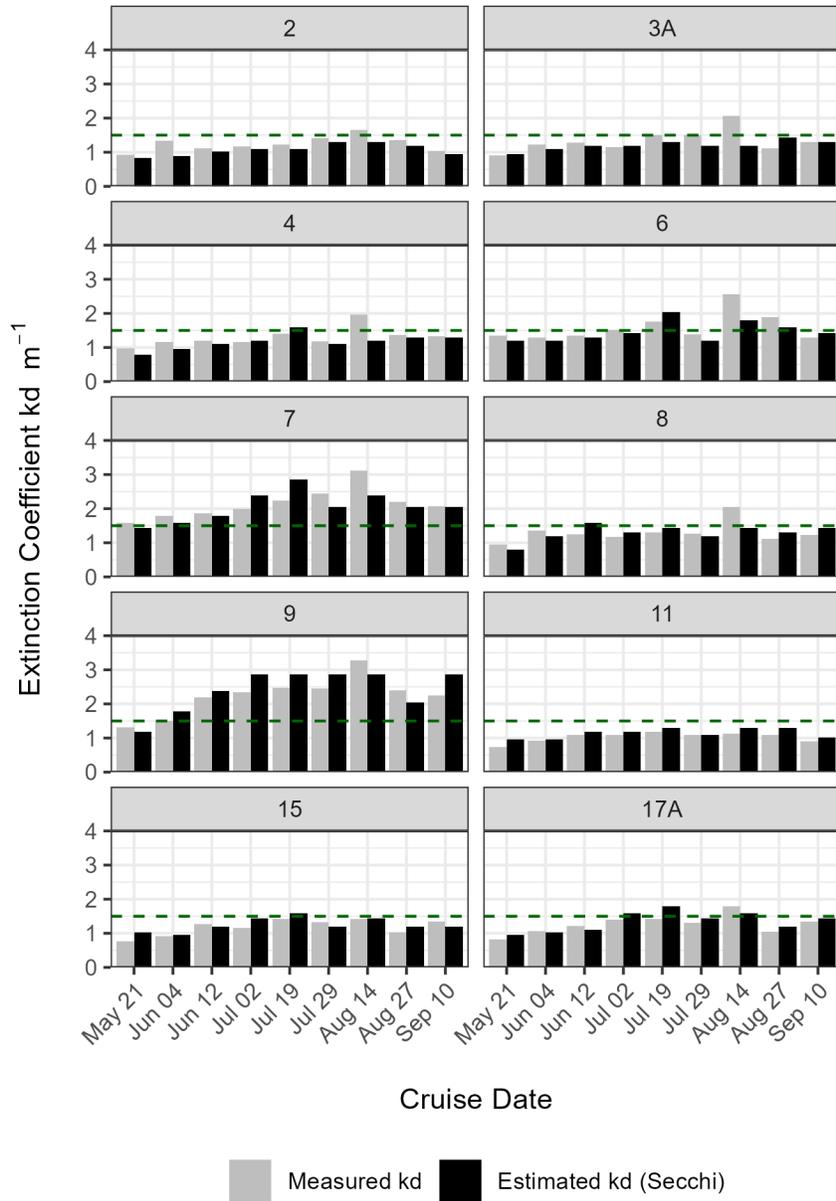
Figure 4.10 Bar graphs of light attenuation measurements (Kd) for each station in the Mill Creek System from May 21 through September 10, 2024, using the estimates of Kd with the Secchi depths and Kd from light profiles. The dashed line in each graph indicates the CBP restoration goal of Kd = 1.5 m^{-1}.

4.5 Seafood and Swimming Safety Monitoring

4.5.1 *Bacterial Contamination*
Figure 4.11 & Table 4.9

During the presentation of the 2006 report to the Calvert County Board of County Commissioners, the issue was raised concerning bacterial contamination of waters in the Mill Creek system. Additionally, the question was raised regarding seafood consumption advisories in the Solomons vicinity. Our water quality monitoring program does not measure fecal coliform bacteria. However, the Maryland Department of Environment produces monthly reports.

MDE has three monitoring stations in the Mill Creek system for classifying shellfish (oyster/clam) harvesting waters along with a sanitary survey. Figure 4.11 depicts a total of 4 stations of interest: Station 005B, a reference Station located off of Sandy Point in the Patuxent River; Station 015A, near station 2 (Boat Shop); Station 109A, in Mill Creek at the mouth of Saint John's Creek near station 4 (Pancake Point); and station 104 in Back Creek, near station 15 (Calvert Marina).
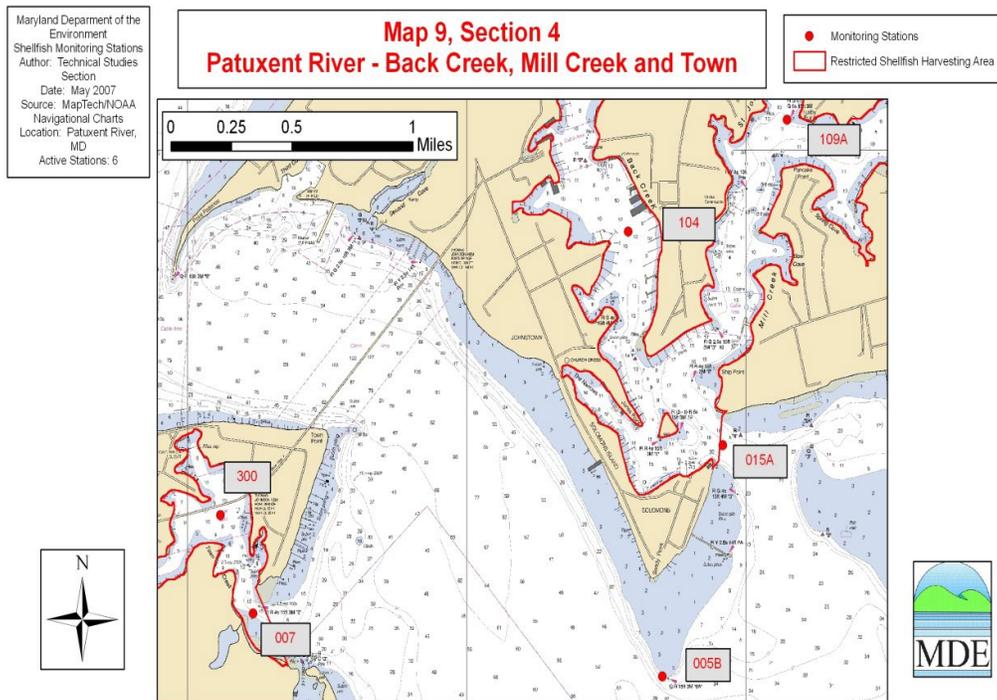
Figure 4.11 Map of the Maryland Department of the Environment (MDE) shellfish monitoring stations in the Mill Creek System.

Fecal coliform is the indicator used for classifying shellfish waters. Water quality standards for shellfish harvesting require that fecal coliform numbers be ≤ 49 MPN/100 mL (MPN = most probable number per 100 milliliters of water). Please note this is a

correction from previous reports which mistakenly stated a fecal coliform threshold of 70 MPN/ 100 mL, which is the threshold for total coliform. To read more on bacteriological monitoring and *E. coli*, please refer to the following web sites:
https://mde.maryland.gov/programs/Water/TMDL/Pages/tmdl_bacteria_monitoring.aspx
https://www.epa.gov/system/files/documents/2021-07/parameter-factsheet_e.-coli.pdf.

Table 4.9 displays the January-December 2024 fecal coliform sample analyses. Note that the peaks in MPN/100 mL do not always coincide with a rain event. The averages for 2007-2024 for each station are listed. Fecal coliform counts were generally within water quality standards at all stations with the exception of one reading of 93 MPN/100 mL in October at station 09-09-109A (on Mill Creek, Pancake Point).

Table 4.9 Fecal coliform counts from a reference station located in the Patuxent River and three stations in the Mill Creek System in 2024. The averages for each station for 2007 through 2024 are listed. Numbers greater than 49 MPN/100 mL are highlighted. Stations that experienced rainfall within 24 hours of sampling are starred (*).

Station ID	Sample Date	Fecal Coliform MP/100mL	Rain	Station ID	Sample Date	Fecal Coliform MP/100mL	Rain
09-04-104	2/22/2024	1		09-04-109A	2/22/2024	4	
	3/26/2024	4			3/26/2024	23	
	4/15/2024	1			4/15/2024	9	
	6/12/2024	9			6/12/2024	1	
	8/13/2024	43			8/13/2024	9	
	10/2/2024	43			10/2/2024	93	
	10/21/2024	9			10/21/2024	9	

Long Term Average				Long Term Average	
2007	27			2007	11
2008	37			2008	12
2009	44			2009	4
2010	33			2010	131
2011	103			2011	50
2012	22			2012	43
2013	14			2013	8
2014	20			2014	26
2015	25			2015	47
2016	39			2016	77
2017	48			2017	30
2018	14			2018	12
2019	31			2019	31
2020	161			2020	146
2021	39			2021	35
2022	31			2022	6
2023	16			2023	21
2024	16			2024	21

Station ID	Sample Date	Fecal Coliform MP/100mL	Rain	Station ID	Sample Date	Fecal Coliform MP/100mL	Rain
09-04-005B	2/22/2024	1		09-04-015A	2/22/2024	4	
	3/26/2024	4			3/26/2024	4	
	4/15/2024	1			4/15/2024	1	
	6/12/2024	1			6/12/2024	4	
	8/13/2024	1			8/13/2024	15	
	10/2/2024	9			10/2/2024	43	
	10/21/2024	1			10/21/2024	23	

Long Term Average				Long Term Average		
2007	5			2007	8	
2008	1			2008	45	
2009	1			2009	5	
2010	5			2010	20	
2011	4			2011	35	
2012	3			2012	15	
2013	2			2013	51	
2014	2			2014	7	
2015	2			2015	95	
2016	2			2016	50	
2017	2			2017	7	
2018	3			2018	4	
2019	7			2019	16	
2020	11			2020	77	
2021	1			2021	17	
2022	1			2022	9	
2023	7			2023	19	
2024	3			2024	13	

4.5.2 *Fish and Shellfish Advisories*
Table 4.10

MDE monitors contaminants in fish and shellfish in Maryland waters. While data specific to the Mill Creek system are not available, data for the Patuxent River and Chesapeake Bay are available and outlined in Table 4.10. Additional information can be found at this website:
http://mde.maryland.gov/programs/Marylander/fishandshellfish/Pages/fishconsumptionadvisory.aspx

Shellfish information can be found at this website:
http://mde.maryland.gov/programs/Marylander/fishandshellfish/Pages/shellfishmaps.aspx

The public can also call MDE (410-537-3906), the USFDA at 1-888-SAFEFOOD, or the Calvert County Health Department at 410-535-3922 for additional information.

Table 4.10 Table of MDE fish advisory recommended consumption by species for the Patuxent River and Chesapeake Bay. Adapted from: https://mde.maryland.gov/programs/Marylander/fishandshellfish/Documents/Maryland_Fish_Advisories.pdf

Species	Waterbody	Recommended Meals per month (for general population/women/children)
Atlantic Croaker	Lower Chesapeake Bay and Tributaries	4/4/4
American Eel	Patuxent River	3/3/3
Black Sea Bass	Lower Chesapeake Bay and Tributaries	2/2/1
Blue Catfish	Patuxent River, Lower Patuxent, Middle and Upper	3/3/1 No limit/no limit/6
Blue Crab Meat	Patuxent River	No limit
Blue Crab Mustard	Patuxent River	Eat Sparingly
Channel Catfish	Patuxent River	2/2/1
Large and Smallmouth Bass	Patuxent River, Lower and Middle Patuxent River, Upper	No limit 3/3/2
Northern Snakehead	Patuxent River, Lower	No limit/ no limit/5
Rainbow Trout and Golden Trout (Hatchery raised)	Calvert County	No limit
Spot	Patuxent River, Lower Patuxent River, Middle Chesapeake Bay and Tributaries	No limit 5/5/4 3/3/2
Striped Bass <28 inches	Chesapeake Bay and Tributaries	No limit/no limit/7, if dark meat and belly fat removed; otherwise, 3/3/2
Striped Bass >28 inches	Chesapeake Bay and Tributaries, and Upper Patuxent	No limit/no limit/5, if dark meat and belly fat removed; otherwise, 1/1/1 every other month
Sunfish	Patuxent River, Middle and Lower Upper Patuxent River	No limit/7 2/2/1
White Perch	Patuxent River, Middle Patuxent River, Upper upper)	5/4/2 No limit
White Sucker	Patuxent (upper)	No limit/8/4;
Yellow Bullhead	Patuxent	5/5/4, 5/5/4

4.5.3 *Swimming Safety*

MDE does not monitor for swimming safety, but they do work closely with the local health departments who determine where beach monitoring should occur. No beaches in the Mill Creek system are monitored by Calvert County. Beaches at Drum Point, Seahorse Beach, and Driftwood Beach on the Chesapeake Bay side are monitored. The website to the Calvert County Health Department Public Beach Monitoring is: http://www.calverthealth.org/community/environmentalhealthservices/cp_publicbeach.htm

For more information, also go to the Maryland Healthy Beach website:
http://www.marylandhealthybeaches.com/

The bacteria indicator used for beach monitoring in estuarine waters is *enterococci*. U.S. EPA regulations state that waters used for Class 1 primary contact (including such activities as swimming, rafting, and kayaking) shall not have fecal coliform counts above 100 fecal coliforms per 100 mL. Note that all Maryland waters are now considered Class 1 and therefore the threshold is lower than stated in previous reports.

4.5.4 *Cases of* Vibrio *Species Infection*
Figure 4.12

Vibrio species are natural inhabitants of sea water. Noncholera *Vibrio* infections are classified into two groups: those that require salt water for growth and those that do not require salt water. The prevalence of noncholera *Vibrio* infections in the United States have increased in recent years. The combination of increased water temperature and salinity where shellfish are harvested may contribute to the increased contamination rates of shellfish. Most *Vibrio* infections are associated with the consumption of contaminated shellfish. However, *Vibrio* can also cause severe skin infections in an open area of skin exposed to warm salt water.

All Vibrio species are reportable in Maryland. In 2024, reported cases in Calvert County remained similar to previous years with no confirmed cases and only 1 probable case. At the time of this report, reported cases for the state of Maryland (37 confirmed and 125 probable cases) had not been finalized but are expected to be similar. The final numbers will be updated in a revised version of this report, if necessary.

The definition of Probable cases was amended in 2017 resulting in a higher number of cases being reported. Prior to this change, only a few probable cases were reported each year. As such, assessment of probable vibrio cases prior to 2017 is difficult. For more information, visit the following websites.
https://ndc.services.cdc.gov/case-definitions/vibriosis-2017/
https://ndc.services.cdc.gov/case-definitions/vibriosis-2012/

Since *Vibrio* species are normally found in the Chesapeake Bay and rivers, it is important not to swim if you have an open skin wound or a compromised immune system. All open skin areas should be evaluated by a health care provider if showing signs and symptoms of infection such as redness, soreness, swelling or drainage. Also, to avoid becoming ill

by consuming a *Vibrio* species, you should only eat cooked shellfish. For more information go to the Center for Disease Control website about *Vibrio*:
https://www.cdc.gov/vibrio/
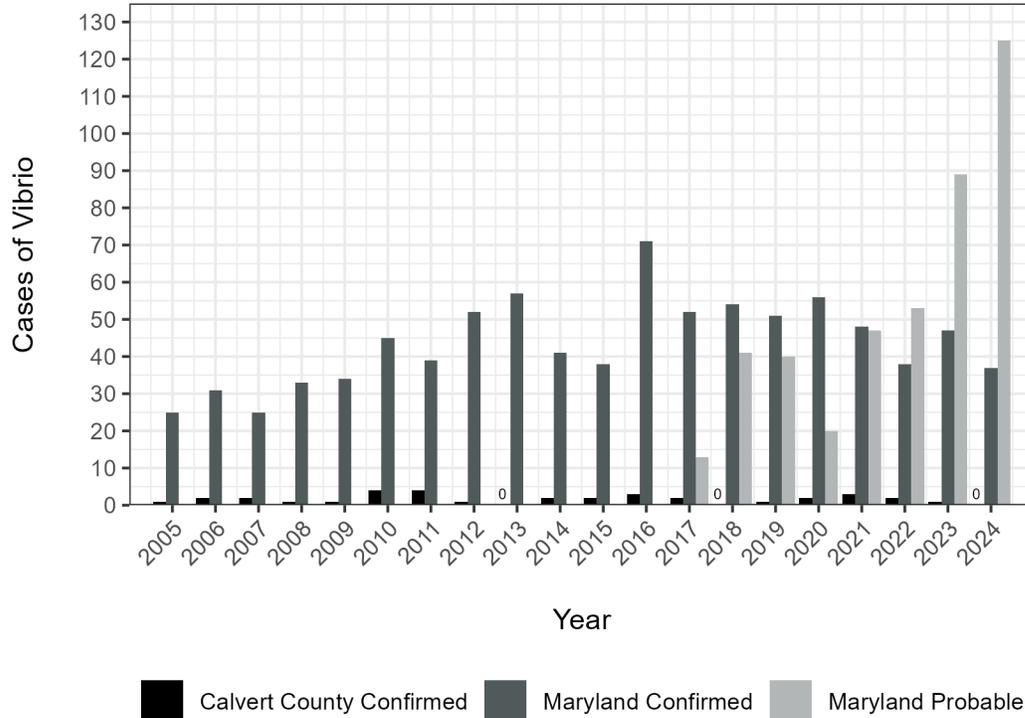
Figure 4.12 Confirmed case counts of *Vibrio* in Calvert County and the State of Maryland for 2005-2024, with probable cases since 2017. Bars represent the total number of reported cases involving all non-cholera *Vibrio* infections. *Note that 2024 Maryland confirmed and probable cases are not final.*

4.6 Sea Nettle Monitoring: Presence /Absence in the Mill Creek Estuary
Figure 4.13

Sea nettles (*Chrysaora quinquecirrha*), are one of the dominant species of jellyfish in Chesapeake Bay. They have three distinct life stages: an adult medusa stage, a juvenile ephyra stage (immature medusa) and a sessile polyp stage. The medusa stage is the umbrella-shaped, free-swimming form that spawns. Combined egg and sperm of male and female medusae produce a larval form (planula) that swims until it is cued to settle. Once attached to substrate, the planula metamorphoses into a sessile polyp. The polyp produces a stack of many small sea-nettles or ephyra through a process called strobilation. Sea nettle polyps can also reproduce asexually through budding and are the overwintering stage that persists through harsher conditions by encysting, while the medusa stage only exists in warmer summer months and dies off every year.

Polyps attach to hard substrate in shallow water, and release 8-10 ephyrae per polyp. The release of ephyrae coincides with the increasing water temperatures as spring approaches

summer (Loeb 1972). Ephyrae continue to grow into their medusae form, which are usually noted in highest abundances in July and August. Sea nettle abundance varies greatly from year to year. Research has shown interannual variation to be explained by flow (Cargo and King 1990), ctenophore abundance, oyster restoration efforts (Breitburg and Burrell 2014; Breitburg and Fulford 2006), climate effects (Purcell 2005), and others. In 2024, sea nettles were not present on any of the May, June, or September cruises (Fig. 4.13) but were present on all July and August cruises. In years with more sea nettles, the abundances of nettles (both ephyrae and medusae) were highest in upper creeks and coves (Breitburg and Burrell 2014), although 2024 saw more patchiness in distribution.
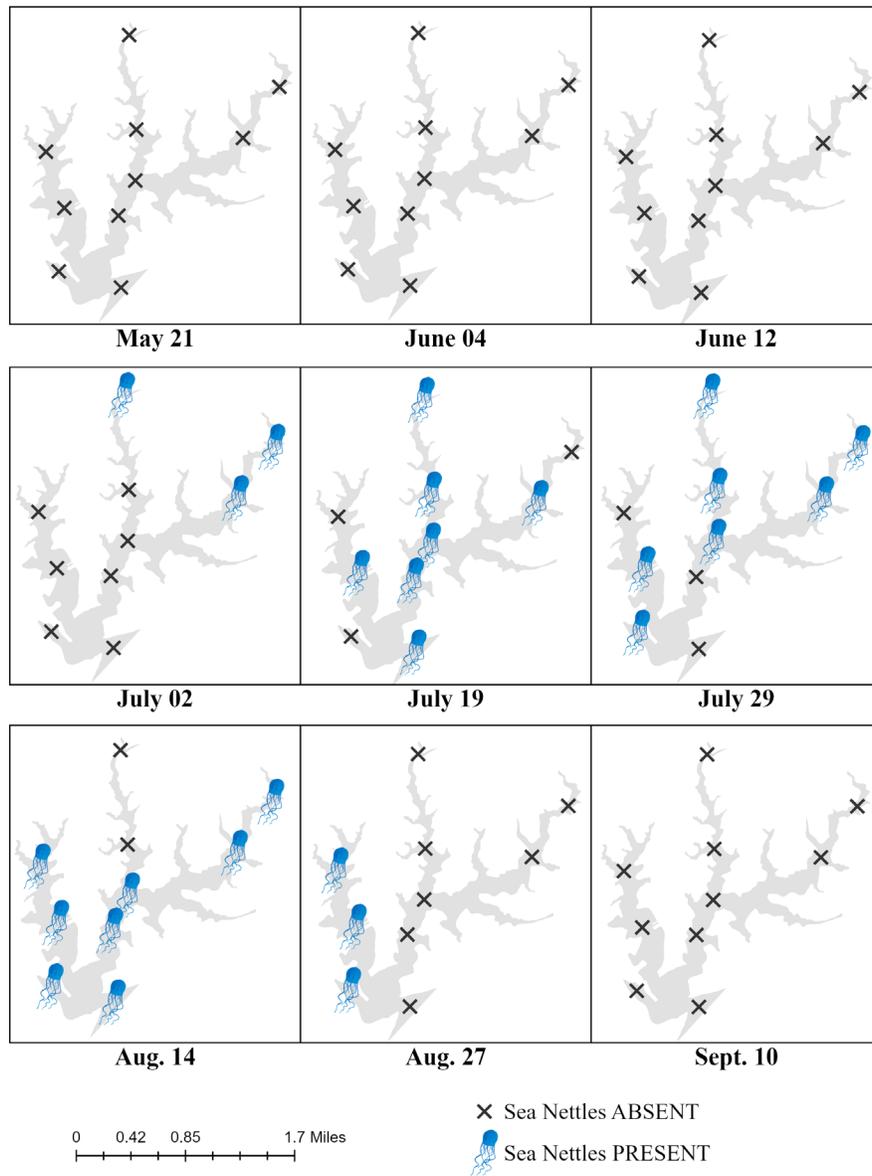
Figure 4.13 Map of the Mill Creek estuary showing presence or absence of Sea Nettles during the 2024 cruises.

5 Mill Creek Sub-estuarine System Long Term Water Quality Trends

To determine if trends were evident in Mill Creek system water quality conditions, we examined data from 5 representative stations: 2-Boat Shop (Mill Creek system mouth), 6-Coles Creek (mid Mill Creek), 7-Ranch Club (upper Mill Creek), 9-Lore's Creek (upper St. John's Creek), and 15-Calvert Marina (mid Back Creek). Two variables were examined including bottom water dissolved oxygen concentrations and surface water active chlorophyll-*a* concentrations. These variables are good indicators of the water quality status of estuarine systems.

5.1 Dissolved Oxygen

Figure 5.1& 5.3A

The average bottom water dissolved oxygen concentrations recorded at these five stations for the summer periods for 1987-1988 and 1990-2024 are summarized in Figures 5.1 and 5.3A. Prior to 2010 bottom water DO was not measured at station 9. Bottom-water dissolved oxygen concentrations in 2024 were higher than in recent years, with an annual
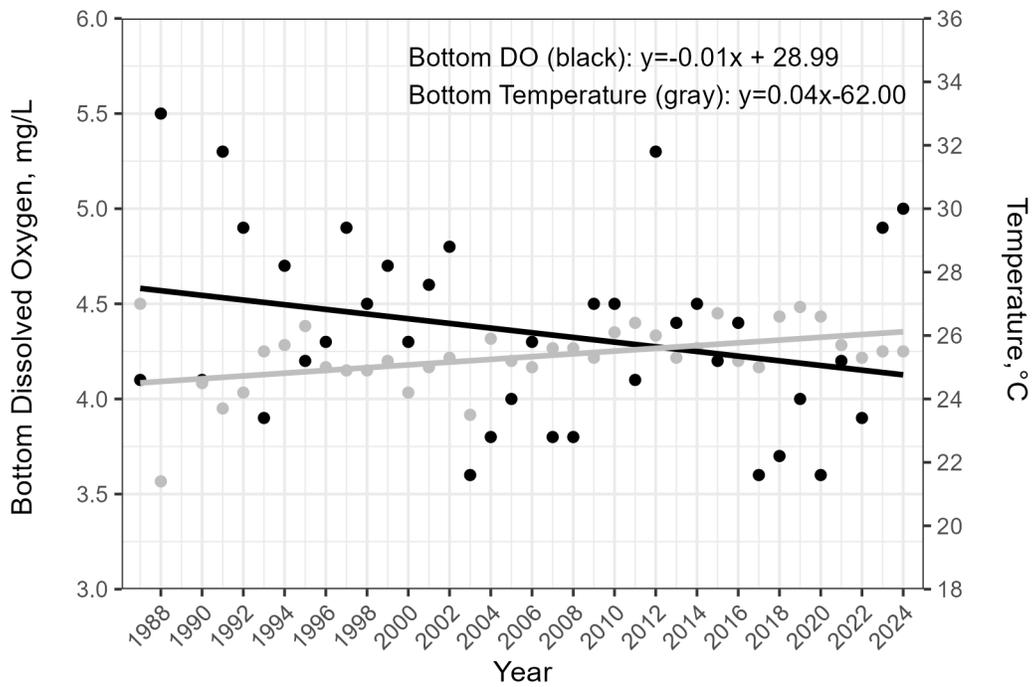
Figure 5.1 Possible trends in average bottom water dissolved oxygen (black) and temperature (grey) in the Mill Creek System using the 5 inter-annual comparison stations. The solid lines indicate a general decline for dissolved oxygen (black) and an increase for temperature (grey). The upward trend for temperature appears to be statistically significant ($r^2 < 0.3$; p-value<0.01) at generally accepted probability levels.

average of 5.0 mg L^{-1} (Figure 5.3A). Even though anoxic conditions (dissolved oxygen concentrations of zero milligrams per liter) have never been observed, hypoxic conditions (less than 2.0 mg L^{-1}) are observed frequently enough to continue monitoring these

trends. Ranking mean bottom water dissolved oxygen concentrations for all years with existing data creates the following pattern from high (better) to low (worse).

1988>2012>1991>**2024**>1992>1997>2023>2002>1994>1999>2001>2010>2009>1998>
2014>2013>2016>1996>2000>2006>2015>1995>2021>1987>1990>2011>2019>2005>
2022>1993>2007>2004>2008>2018>2017>2020>2003

The regressions in Figure 5.1 visually indicate that although average bottom water dissolved oxygen (black) improved in 2023 and 2024, it may be declining (worsening) over the years the system has been monitored, while bottom water temperatures (grey) have increased (worsening). The warming trend appears to be statistically significant. Analysis of the raw data (not shown here) also indicates a weak inverse relationship between bottom water dissolved oxygen and temperature overall and at each station. Note that two years of improvement are not typically adequate to determine a new direction using linear regression analysis. If we continue to see improvement, a GAM (generalized linear model) analysis might be more appropriate to capture a potential nonlinear pattern of decline or improvement.

5.2   Chlorophyll-*a*
Figure 5.2 & 5.3B

Surface active chlorophyll-*a* concentration means for stations 2, 6, 7, 9, and 15 from 1987 through 2024 are depicted in Figure 5.2. Ranking mean surface water active chlorophyll-*a* concentration for all years with existing data creates the following pattern from low (better) to high (worse):

1991<1992<1995<1999<2002<2000<1997<1993<2023<2022<2012<2016<**2024**<2001<
1994<2006<2015<1987<2005< 2021<2013<2009<2008<2017<1996<2014<2018<
2004<2010<1990<2007<2020<1998<2019<2011<2003

The surface mean active chlorophyll-*a* concentration of 16.27 µg L^{-1} in 2024 was higher than the 2023 average of 14.49 µg L^{-1} (Figure 5.3B). This yearly average is slightly lower than the 1987-2024 average concentration of 18.73 µg L^{-1} and is higher than the long-term median (14.2 µg L^{-1}). The highest observed average yearly concentration, 45.21 µg L^{-1} occurred in 2003, an especially wet year, and was more than twice as high as the long-term average.

The regression in Figure 5.2 indicates that average surface water active chlorophyll-*a* may be increasing over the years. Although this pattern is not statistically significant based on the most recent time-series, the increase can be expressed as a decadal change of about 1.3 µg L^{-1} chlorophyll-*a* every 10 years. While this is a small change, it seems to be progressive and that is reason for concern.   In 1987, average chlorophyll-*a* concentration was about 17.36 µg L^{-1}, well below what is considered to be a bloom concentration (> 20 µg L^{-1}). For the past 20+ years, annual average concentrations are much closer or even above the bloom concentration threshold. More recently, mean chlorophyll levels have been on the decline since 2019 but increased slightly in 2024.

The chart shows: y=0.13x-242.94, r^2=0.01 with Y-axis "Surface Active Chlorophyll, µg/L" and X-axis "Year"
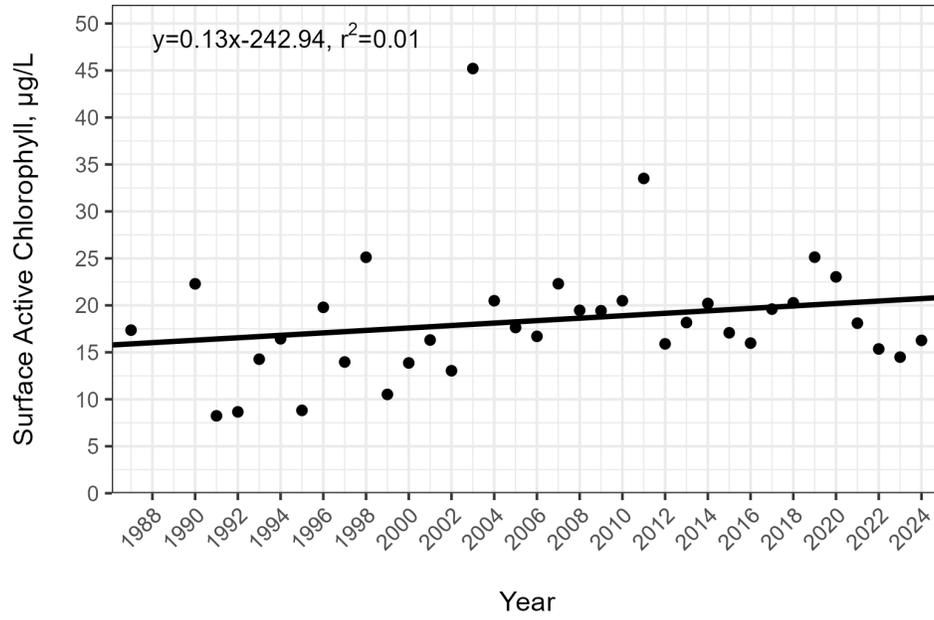
Figure 5.2 Averaged surface water chlorophyll-*a* in the Mill Creek System using the 5 inter-annual comparison stations. The upward pattern indicated is not statistically significant (p>0.05).
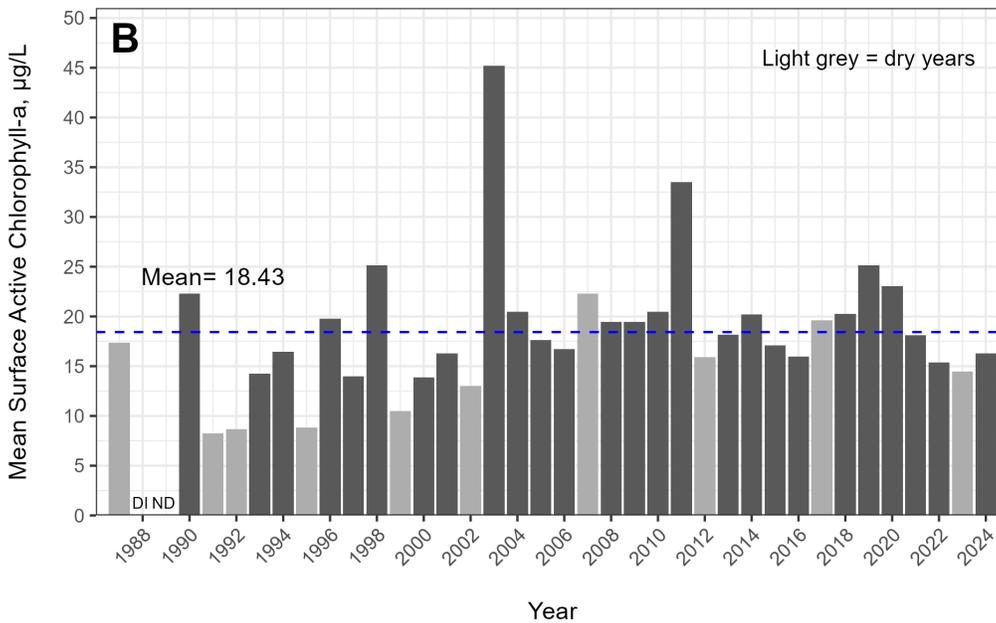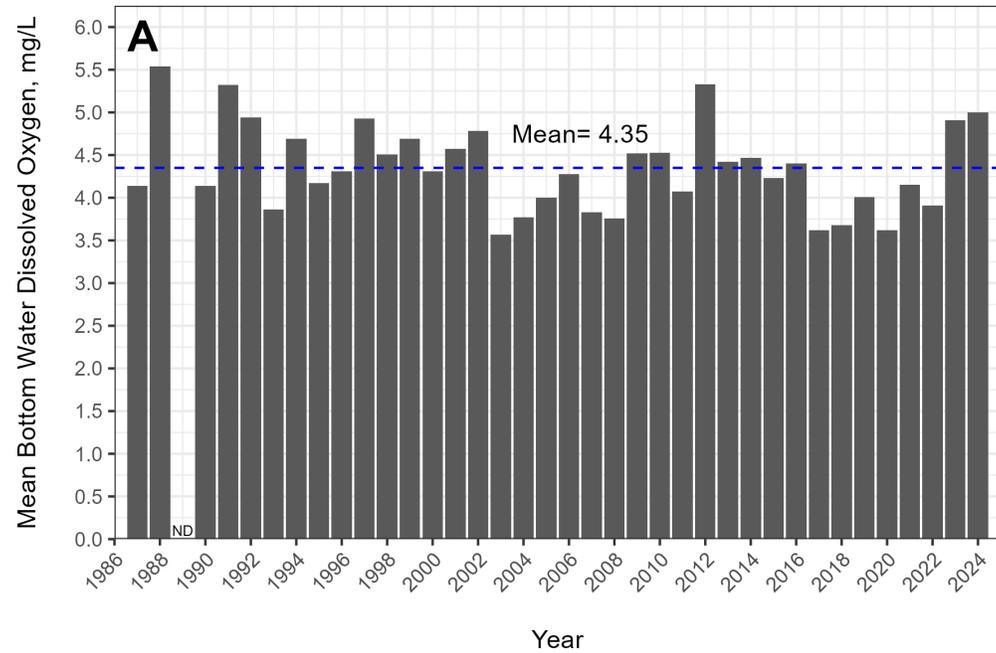
Figure 5.3 A&B Bar graphs of (A) bottom water mean dissolved oxygen concentrations at the inter-annual comparison sites (stations 2, 6, 7, 9, and 15) from 1987 through 2024, and (B) mean surface water active chlorophyll-*a* concentrations at the inter-annual comparison sites (stations 2, 6, 7, 9 and 15) from 1987 through 2024. In graph B, the dry years based on river discharge are indicated by the lighter bars. DI = incomplete dataset. ND = Study was not funded during 1989.

5.3   Algal Blooms

Figure 5.4

For this program, an algal bloom is defined as any concentration of active chlorophyll-*a* greater than 20 µg L^{-1}. Occurrences of surface algal blooms at the five inter-annual comparison stations were averaged. The overall average for the time series was 11 surface blooms each year. 2024 was an average year with eleven surface blooms ranging from 20.77 to 38.55 µg L^{-1}. In comparison, zero surface blooms were recorded in 1999, while 2003 produced the study maximum of 29 blooms. Ranking occurrences of surface algal blooms since 1987 gives the following pattern from lowest (better) to highest (worse) number of blooms:

1999<1995<2002<1991=1992<2005<2012<1997=2000<1993<1987=1990=2013=2023< 2006=2021<2009=2022=**2024**<1994=2001=2015=2016<1996=2008=2014=2017=2020< 2004=2010<2018<2019<1998<2007<2011<2003
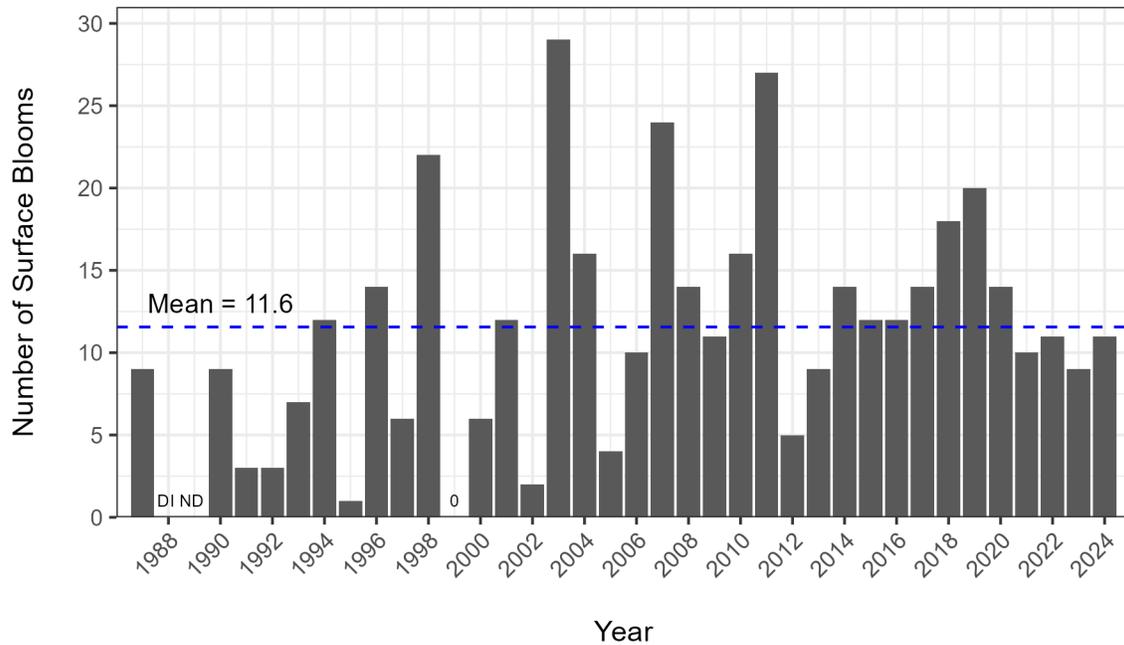
Figure 5.4 Bar graph of surface chlorophyll-a blooms in the Mill Creek System at the inter-annual comparison stations 2, 6, 7, 9 and 15 from 1987 through 2024. Note that chlorophyll-a concentrations measuring greater than 20 µg L-1 were defined as blooms. DI = Data set for 1988 was incomplete. ND = No study was funded in 1989.

6 Calvert County Tidal Tributaries: Water Quality Monitoring Results and Discussion

Our monitoring since 2009 in a number of tidal creeks along the Patuxent and Western Chesapeake shores of Calvert County is building into a robust database of water quality measurements. Here we outline results from 2024 and begin to provide some context for these measurements within the framework of the up to sixteen years of data now available for interpretation.

6.1 Lower Patuxent River Tributaries

Twelve stations located in four lower Patuxent river tributaries were visited three times in 2024 (June, July, and August) to capture summer water quality conditions in these systems. The stations were located in 4 creeks in the lower Patuxent River estuary, all south of Broomes Island and all in Calvert County. Included were: 3 stations in Hellen's Creek, 4 stations in Saint Leonard Creek, 3 stations in Island Creek and 2 stations in Hungerford Creek. It may be of note that due to extended high temperatures and inclement weather, the sampling plan was modified for some creeks.

All water quality data collected during the 2024 monitoring study in the Lower Patuxent River Tributaries are listed in Appendix II by station and date.

6.1.1 *Water Column Clarity using Secchi Disk Readings*
Figure 6.1

The Lower Patuxent tributary Secchi disk measurements were comparable in magnitude to the Mill Creek system, ranging from 0.2 to 1.1 meters. The upper-most stations (i.e. higher station numbers) in Island Creek and St. Leonard Creek had lower clarity compared to down-stream stations, while Secchi depths were similar between lower and upper stations on Hellen's Creek and Hungerford Creek. Water clarity at the St. Leonard Creek stations was generally higher compared to those on other creeks. Secchi depths on all creeks appeared to be relatively consistent over the summer with only slight variations between months. Note that Secchi depth measurements were not collected on June 7th due to an equipment malfunction.

6.1.2 *Dissolved Oxygen*
Figure 6.2

In the Lower Patuxent Tributaries, surface water dissolved oxygen concentrations ranged from 0.78 to 11 mg L^{-1}. Bottom water concentrations ranged from 0.70 to 9.46 mg L^{-1}. As a part of the Chesapeake Bay Program, water quality criteria have been developed for dissolved oxygen concentration in estuarine waters. The criterion (30 day average) is 5.0 mg L^{-1} for shallow water systems such as those in the Patuxent creeks and the Mill Creek system. Oxygen levels in the lower Patuxent tributaries fell below this minimum criterion at least one time over the summer in the bottom water at all St. Leonard Creek stations, in the down-stream and mid-stream stations on Hellen's Creek (HLN1, HLN2), and the upper-most station of Island Creek (IC3). Surface waters of the uppermost

stations of Island Creek (IC3) and St. Leonard Creek (SLC3, SLC4) also fell below 5.0 mg L^{-1}. Hypoxic conditions (<2 mg L^{-1}) were measured 6 times in 2024. All instances occurred on St. Leonard Creek on July 15th (SLC1, SLC2, SLC3) and on August 15th (SLC2, SL3, SLC4). By comparison, 8 instances of hypoxia were recorded in 2023 and occurred at all St. Leonard Creek and Island Creek stations, and at the mid-station of Hellen's Creek (HLN2). The majority of hypoxic cases recorded in 2021 and 2022 also occurred at St. Leonard Creek (9 out of 12 times and 7 out of 9 times, respectively).

6.1.3 Active Chlorophyll-a
Figure 6.3

Surface water active chlorophyll-*a* concentrations ranged from 11.57 to 68.12 μg L^{-1}. Bottom water concentrations ranged from 5.52 to 52.91 μg L^{-1}. As in 2022 and 2023, the highest surface and bottom concentrations occurred at the uppermost Island Creek station (IC3). The highest surface concentration was measured on June 7th and the highest bottom concentration was measured on both July 15th and August 15th. As in 2022 and 2023, the highest surface and bottom concentrations occurred at the upper-most Island Creek station (IC3) on June 7th (surface) and on July 15th and August 15th (highest bottom concentrations).

In 2024, nineteen surface blooms were recorded (active chlorophyll-*a* concentrations > 20 μg L^{-1}) occurring in 10 of the 12 stations monitored. By comparison, fifteen surface blooms were recorded in 2023 at 9 stations, and five surface blooms were recorded in 2022 at 3 stations.
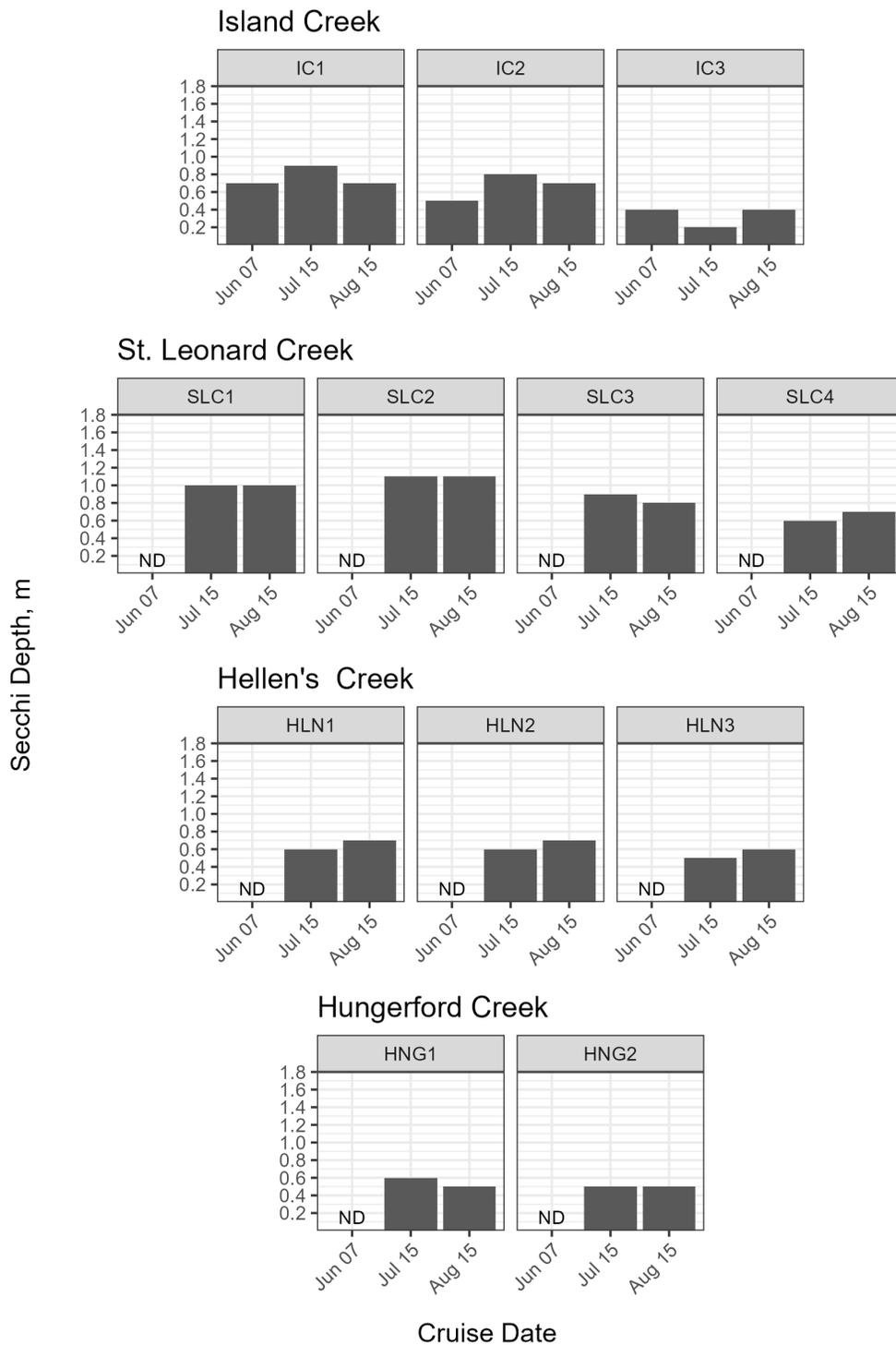
Figure 6.1 Bar graphs of water column Secchi disk measurements for each station from June, July, and August 2024. "ND" indicates missing data due to equipment malfunction.

Figure 6.2 Bar graphs of surface and bottom water dissolved oxygen measurements for each station from June, July, and August 2024. Values below 2 mg L^{-1} (dashed line) are considered hypoxic. Note that no bottom sample ("ND") was collected at IC3 on June 7th due to shallow depth.
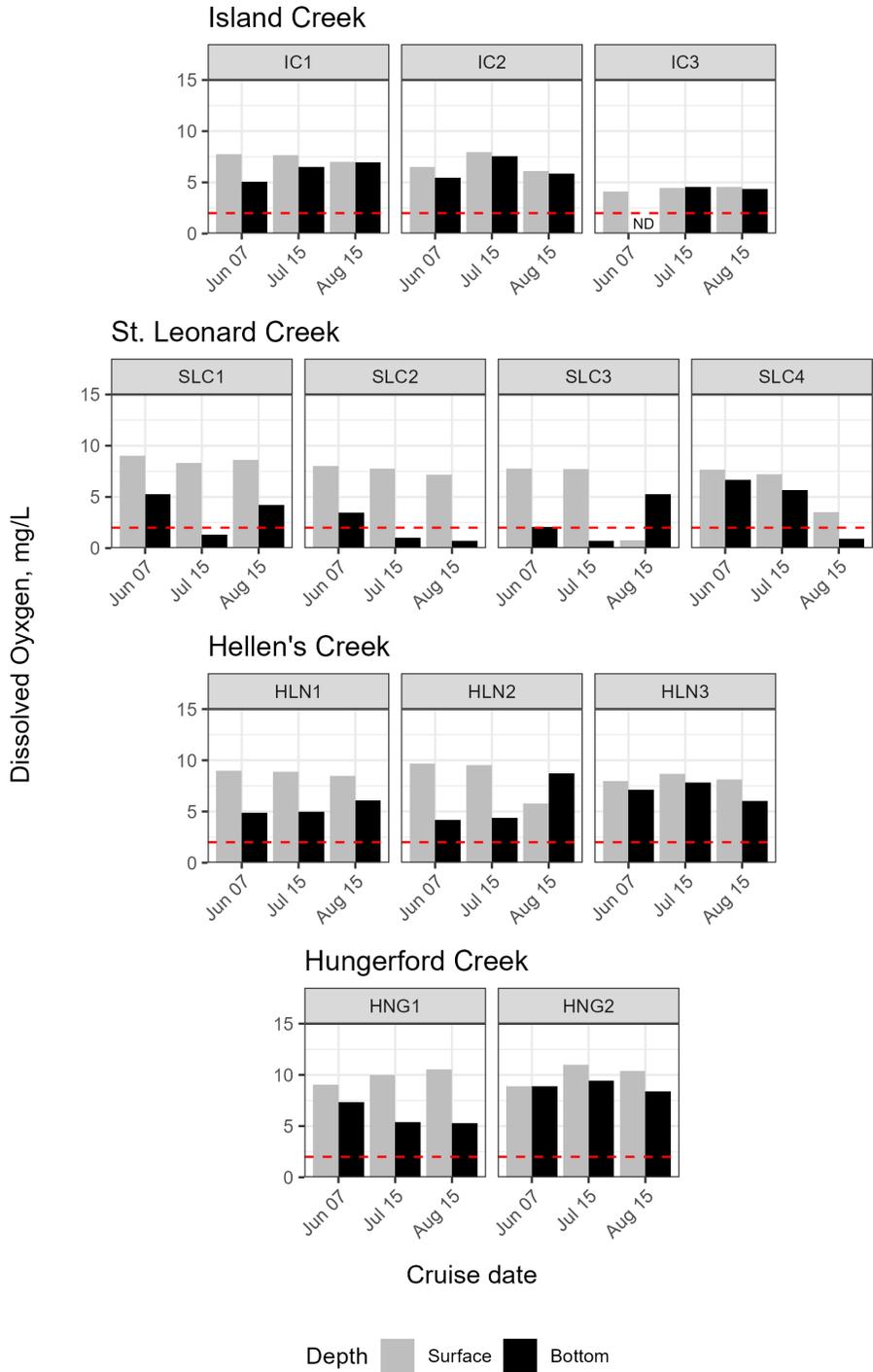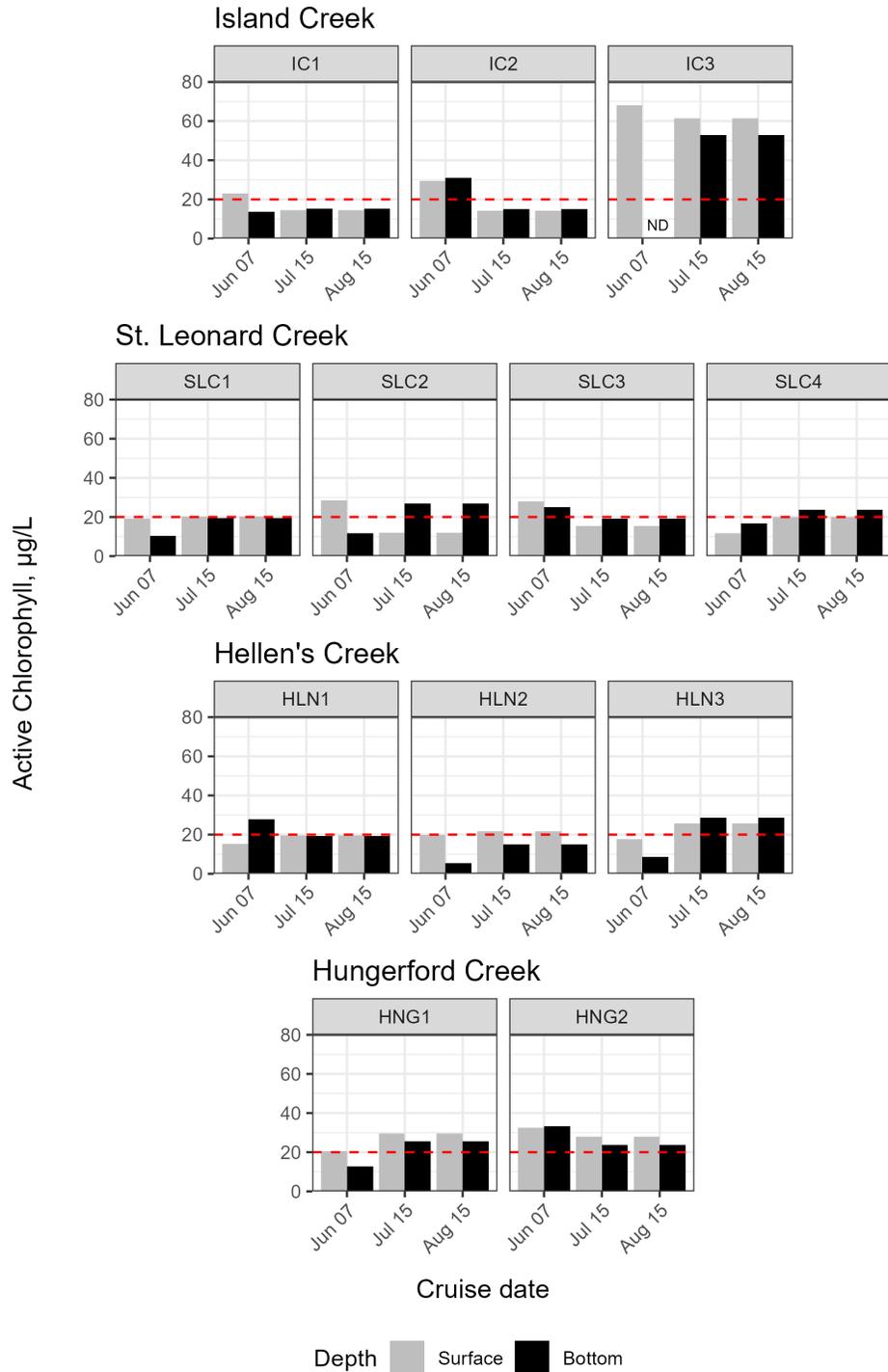
Figure 6.3 Bar graphs of surface and bottom water active chlorophyll-*a* measurements for each station from June, July, and August 2024. Values above 20 µg L⁻¹ (dashed line) are considered blooms. Note that no bottom sample ("ND") was collected at IC3 on June 7th due to shallow depth.

6.2 Upper Patuxent River Tributaries

Nine stations located in three upper tributaries in the upper Patuxent estuary were examined three times (June, July, and August) in 2024, to catch the peak of summer conditions in these systems. Each of these tributaries (Battle Creek, Hunting Creek, and Hall Creek) are north of Broomes Island and in Calvert County. Three stations were monitored in each creek. As in 2012-2023, Battle Creek was sampled with the Lower Patuxent Creeks while Hall and Hunting Creeks were usually sampled together on a different day. In June 2024, Hunting and Hall Creek were sampled two weeks later than the rest of the Calvert Creeks stations due to inclement weather and were sampled on separate mornings in July due to inclement weather and extreme heat. All water quality data collected during the 2024 monitoring study in the Upper Patuxent River tributaries are listed in Appendix II by station and date.

6.2.1 *Water Column Clarity using Secchi Disk Readings*
Figure 6.4

The tributary Secchi disk readings were generally lower than the Mill Creek system and the lower Patuxent tributaries, ranging from 0.2 to 0.7 meters. The lowest water clarity (0.2 m) was recorded at all Hunting Creek stations and at the uppermost Battle Creek station (BAT3) on July 15th and 16th. Water clarity was generally lowest on Hunting Creek ranging from 0.2 to 0.4 m with an average of 0.3 m, while Hall Creek and Battle Creek averaged 0.4 and 0.5 m, respectively. Secchi disk readings in the range of 0.3 to 0.9 m are not supportive of SAV growth. We should note that water clarity in the mainstem of the Patuxent River is also poor in the vicinity of these creeks, where both the creeks and the mainstem Patuxent are flanked by extensive tidal marshes that export light-attenuating materials to the creeks. Note that Secchi depth measurements were not collected on June 7th due to an equipment malfunction.

6.2.2 *Dissolved Oxygen*
Figure 6.5

Surface water dissolved oxygen concentrations ranged from 3.72 to 9.32 mg L^{-1} with the peak measurement occurring at the downstream station of Battle Creek (BAT1) on August 15th. Bottom water concentrations ranged from 1.11 to 7.57 mg L^{-1}. Overall, surface DO was comparable to the Mill Creek system and the lower Patuxent, averaging 6.72 mg L^{-1}. As in previous years, Hall and Hunting Creek generally exhibited a well-mixed water column, with similar surface and bottom DO values and concentrations that suggest equilibrium with the atmosphere.

Dissolved oxygen in surface waters of all three creeks was generally recorded at above 5.0 mg L^{-1} but dropped below this threshold at the mid station of Hunting Creek (HUN2) in July and at both upstream stations in August (HUN2, HUN3).

In contrast, approximately one third of the bottom water measurements were lower than 5.0 mg L^{-1} and one instance of hypoxia (< 2.0 mg L^{-1}) was recorded at the lower Battle Creek station (BAT1) in August. Battle Creek demonstrated declining levels of dissolved

oxygen in bottom waters over the summer, while levels in surface waters fluctuated both temporally and spatially. At the lower station of Hunting Creek, both surface and bottom waters remained similar over the summer while the mid and upper stations experienced a decline in dissolved oxygen over the summer that was more pronounced between June and July. Dissolved oxygen in the surface and bottom waters of Hall Creek slightly declined from June to July then increased in August.

6.2.3 *Active Chlorophyll-a*
Figure 6.6

Surface water active chlorophyll-*a* concentration ranged from 20.91 to 75.75 µg L^{-1}, and bottom water readings ranged from 9.05 to 60.22 µg L^{-1}. All surface samples (27 total) collected for Hall, Hunting, and Battle Creeks indicated blooms (> 20 µg L^{-1}). The peak surface active chlorophyll-a concentration (75.75 µg L^{-1}) occurred at the upstream station of Hunting Creek (HUN3) on June 27th.   Surface and bottom levels were relatively low in Battle Creek, except in the upstream station (BAT3) which was higher than the upstream station of Hall Creek (HAL3) in July and August.   Surface and bottom water chlorophyll were often comparable with the exceptions of two Battle Creek stations (BAT1, BAT3) on June 7th.
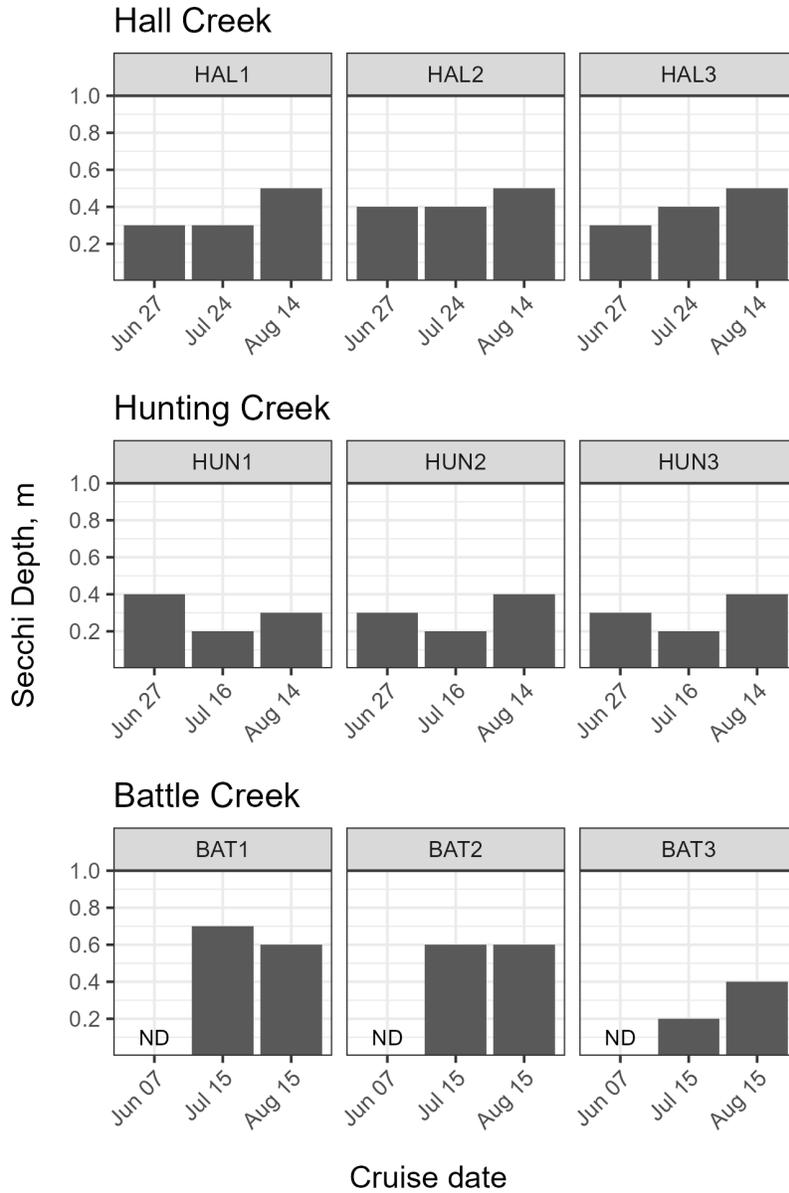
Figure 6.4 Bar graphs of water column Secchi disk measurements for each station from June, July, and August 2024. "ND" indicates missing data due to equipment malfunction.

Figure 6.5 Bar graphs of surface and bottom water dissolved oxygen measurements for each station from June, July, and August 2024. Values below 2 mg L^{-1} (dashed line) are considered hypoxic. "ND" indicates no data.
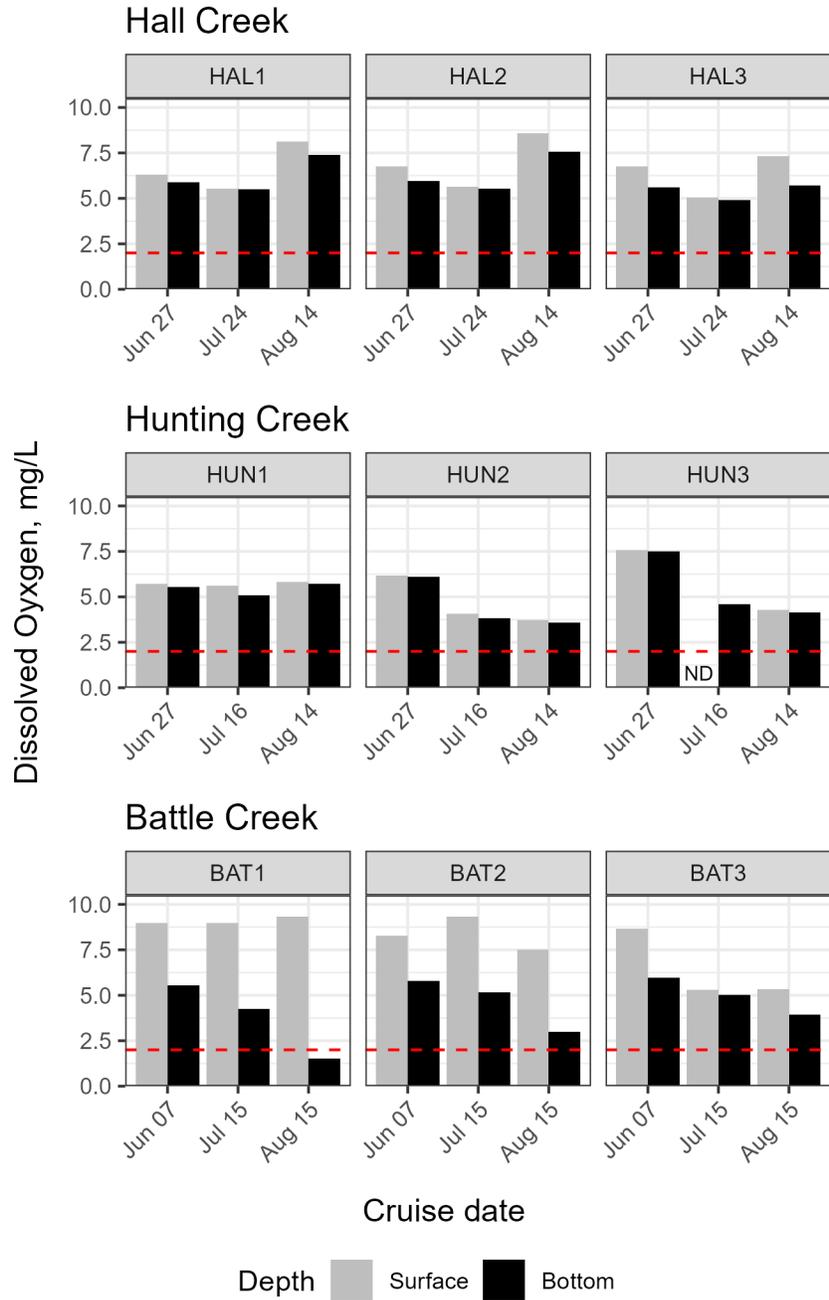
Hall Creek
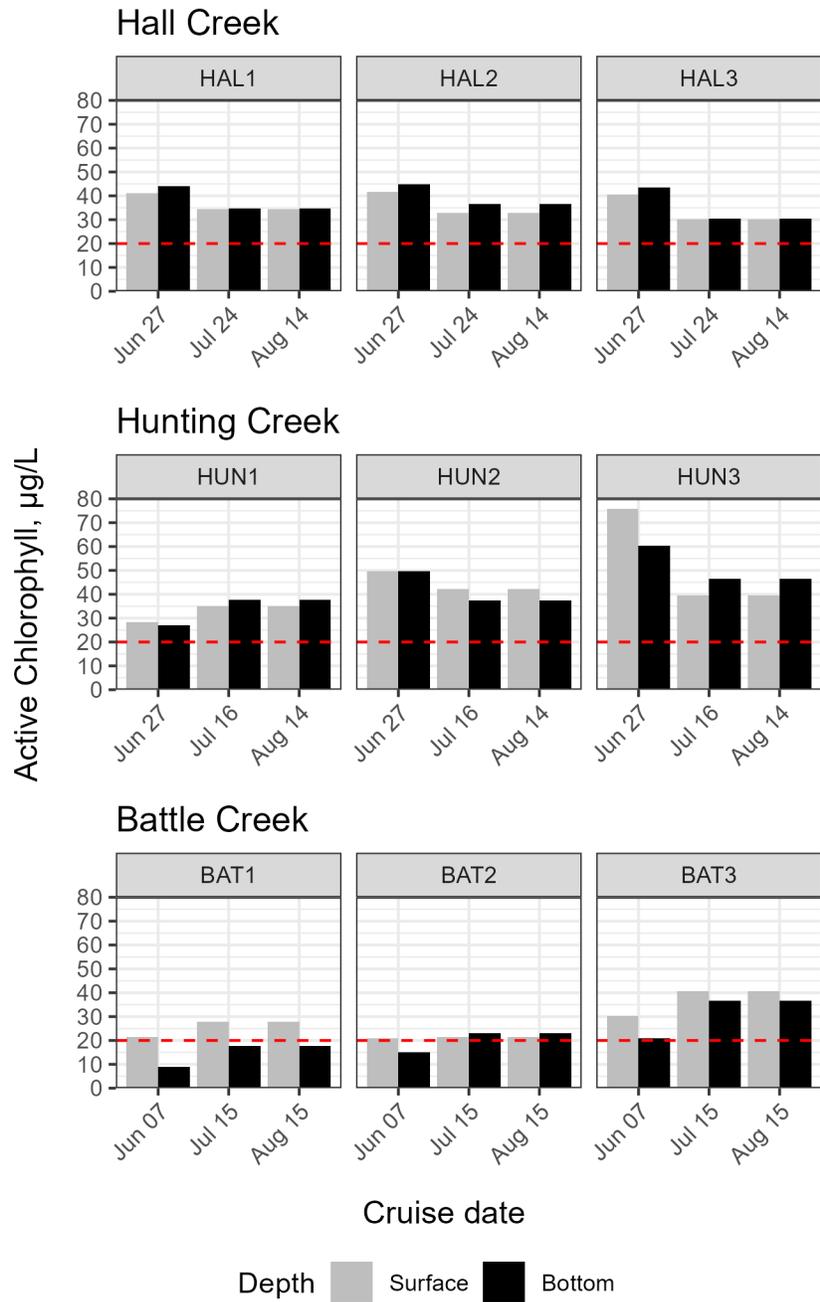

Hunting Creek

Battle Creek

Figure 6.6 Bar graphs of surface and bottom water active chlorophyll-*a* measurements for each station from June, July, and August 2024. Values above 20 μg L^{-1} (dashed line) are considered blooms.

6.3 Chesapeake Bay Western Shore Tributaries

Eleven stations located in four Chesapeake Bay Western shore tributaries were examined three times (June, July, and August) during 2024, to measure summer water quality conditions in these systems. The stations were located in 4 creeks on the Chesapeake Bay Western shore in Calvert County including 3 stations on Fishing Creek, 3 stations on Plum Point Creek, 3 stations on Parkers Creek, and 2 stations at Flag Harbor.   Due to extreme heat and inclement weather in July, Plum Point creek was sampled in the morning and Fishing Creek was sampled on a separate day over a week later.

All water quality data collected during the 2024 monitoring study in the Western Shore tributaries are listed in Appendix II by station and date.

6.3.1 *Water Column Clarity using Secchi Disk Readings*
  Figure 6.7

The tributary Secchi disk readings were comparable to those of the Upper Patuxent tributaries, ranging from 0.2 to 1.0 meters, which is not sufficient to support healthy SAV communities in most circumstances. Water clarity at Flag Harbor improved from June to July but declined slightly over the summer at Fishing Creek sites. Secchi depths at the lower and mid stations on Parkers Creek (WR and MC) declined over the summer while the uppermost station (BC) fluctuated only slightly and remained low. Plum Point Creek exhibited relatively low water clarity and remained fairly consistent over the summer with the exception of the lower station (PLM1) where water quality improved by mid-August. By comparison, overall water quality was similar to ranges recorded in the past two years (2022 – 0.2 to 0.8 m, 2023 – 0.3 – 0.9 m).   Note that Secchi depth measurements were not collected at Flag Harbor and one Plum Point Creek station (PLM2) on August 13th due to an equipment malfunction.

6.3.2 *Dissolved Oxygen*
  Figure 6.8

Surface water dissolved oxygen concentrations ranged from 1.92 to 11.15 mg L^{-1}. Bottom water concentrations ranged from 0.99 to 10.15 mg L^{-1}. Oxygen conditions were below 5.0 mg L^{-1} at 9 of the 11 stations at some point during the summer.   Stations on Fishing Creek experienced a slight decline in general over the summer, although the dissolved oxygen levels increased slightly at the upper station (FSH3) in August.   From June to July dissolved oxygen levels at Plum Point Creek and Flag Harbor stations dipped to levels near or below the 5.0 mg L^{-1} threshold but by mid-August had recovered to levels similar to those measured in June. Levels at the lower stations (WR, MC) of Parkers Creek were generally above the threshold. The uppermost station (BC) was generally below 5.0 mg L^{-1} but surface waters exceeded the threshold on July 18th. All stations on Parkers Creek experienced the lowest concentrations in August.

Hypoxic conditions (< 2 mg L^{-1}) were recorded in surface and bottom waters, at the upstream stations on Parker's Creek (BS) in mid-August. However, hypoxic conditions were not documented at Flag Harbor, Plum Point Creek, or Fishing Creek. Hypoxia in

surface waters means that in addition to the loss of benthic habitat, organisms will struggle to find suitable habitat in the entire water column.

6.3.3 *Active Chlorophyll-a*

Figure 6.9

Surface water active chlorophyll-*a* concentration ranged from 7.53 to 86.19 µg L^{-1}. Bottom water readings ranged from 10.77 to 90.07 µg L^{-1}. There were 24 surface blooms (concentrations greater than 20 µg L^{-1}) in 2024 compared to 12 blooms in 2023 and 19 blooms in 2022. All stations experienced at least one bloom over the summer. Chlorophyll levels were generally above 20 µg L^{-1} at the Western Shore sites with the exception of Flag Harbor. Both Plum Point Creek and Parkers Creek experienced the overall highest chlorophyll levels at their mid-creek stations (PLM2, MC), while Fishing Creek and Flag Harbor exhibited similar concentrations between their respective stations.
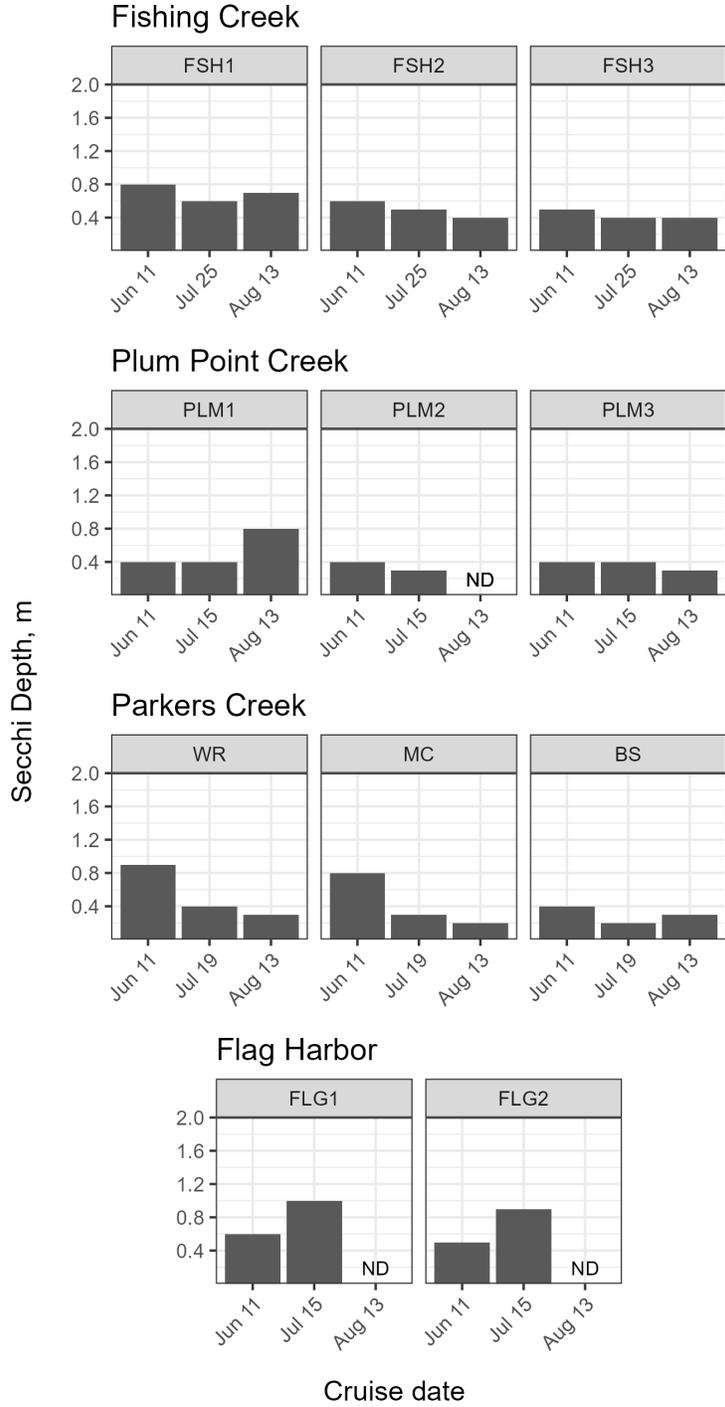
Figure 6.7 Bar graphs of Western Shore water column Secchi disk measurements for each station from June, July, and August 2024. "ND" indicates no data due to equipment malfunction.

Figure 6.8 Bar graphs of Western Shore surface and bottom water dissolved oxygen measurements for each station from June, July, August, and September 2024. Values below 2 mg L^{-1} (dashed line) are considered hypoxic. Data was not recorded where depths were too shallow (< 1 m), indicated by "ND".
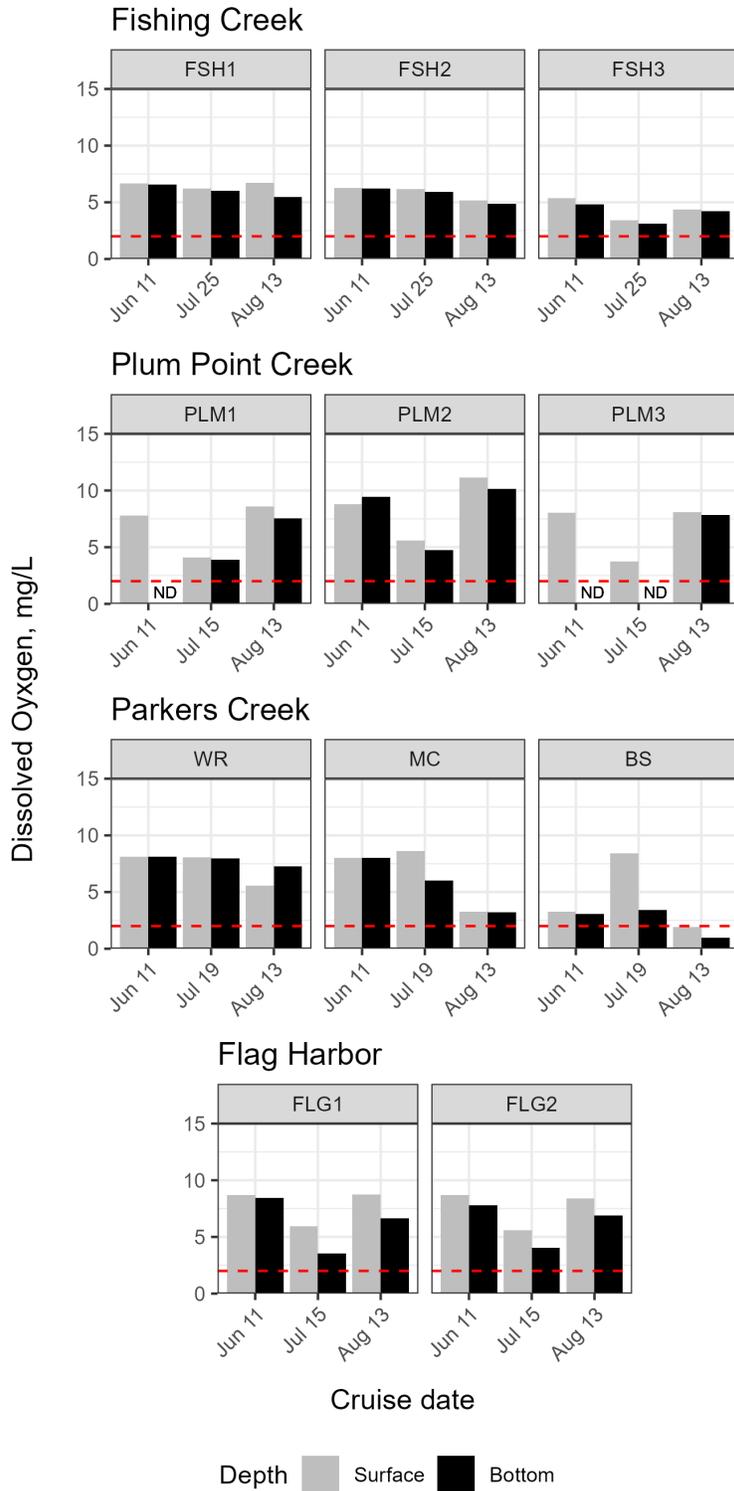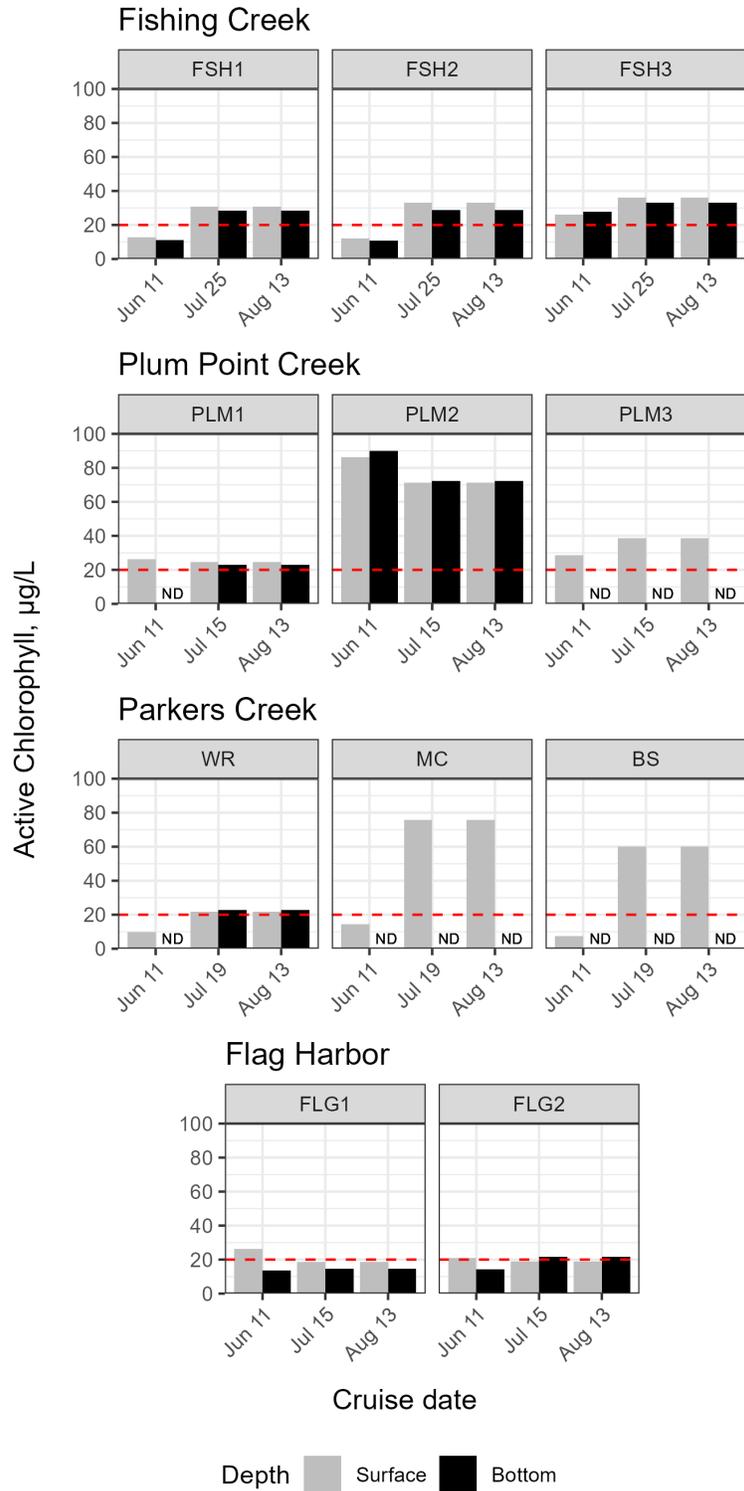
Figure 6.9 Bar graphs of Western Shore surface and bottom water active chlorophyll-*a* measurements for each station from June, July, August, and September 2024. Values above 20 μg L^{-1} (dashed line) are considered blooms. Samples were not collected ("ND") where depths were too shallow (< 1 m).

7 Calvert County Tidal Tributaries: Inter-annual Comparisons

The monitoring scheme for shallow water environments (near-shore waters and small tributaries) adopted by the EPA Chesapeake Bay Program involves a rotation of sampling locations that are maintained three consecutive years of sampling at a given location. This 3-year scheme is meant to be long enough to capture the high degree of variability in water quality typically associated with estuarine ecosystems caused by inter-annual (and inter-seasonal) differences in weather conditions. For example, in dry years (or dry seasons) freshwater flow and associated nutrient, sediment and organic matter loads from the adjacent landscape are generally reduced while the opposite is the case during wet years. The three-year sampling schedule is an attempt to capture at least a portion of this variability and thus arrive at an average "water quality status" for each location.

In contrast, the Calvert County Monitoring Program takes a longer-term monitoring approach that is advisable because identification of trends in water quality is a central issue rather than just establishing a water quality status for various locations. The lower Patuxent Creeks (Island Creek, St Leonard Creek, and Hellen's Creek) have been monitored for sixteen summer seasons (2009-2024). The upper Patuxent River creeks (Battle Creek, Hunting Creek, and Hall Creek) have been monitored for fifteen summer seasons. The Chesapeake Bay Western shore creeks have been monitored for fourteen summer seasons and Hungerford Creek (lower Patuxent) has been monitored for thirteen seasons. Parkers Creek (western shore) has been monitored for twelve years as a part of this program. Here we present average tributary conditions during summer (June, July, and August) for each sampling year and long-term tributary averages of the water quality collected in each tributary.

7.1 Lower Patuxent Tributary Comparisons

7.1.1 *Water Column Clarity using Secchi Disk Readings*
Figure 7.1

Summer average water clarity, as indicated by Secchi disk depth in the Patuxent Creek systems was relatively stable between years. Water clarity was generally insufficient for SAV growth in the majority of years in the Patuxent creeks. In recent years, there has been notable SAV growth in the spring period in Mill Creek and some lower Patuxent creeks. This SAV is a species known as *Zannichellia,* which grows in spring and senesces and disappears before our sampling typically begins.

Over the years of sampling, Hungerford Creek had the minimum average Secchi Disk depth (0.6 m) across creeks, while St. Leonard Creek had the maximum average of 1.0 m. Average Secchi depths were near or higher than the long-term mean for each creek from 2020 to 2023 but dropped below the long-term mean for all creeks in 2024.

Over the sixteen years of sampling, the minimum Secchi disk measurement of 0.2 m occurred on several occasions over the years. The maximum (best water clarity) measurement (1.6 m) was recorded in 2022 on St. Leonard Creek. All creeks appear to be improving but do not exhibit statistically significant trends.

7.1.2 *Dissolved Oxygen*

Figure 7.2

Average bottom dissolved oxygen in 2024 was above long-term means for all Lower Pax creeks. The Lower Patuxent creeks experienced an increase in average bottom water dissolved oxygen with the exception of St. Leonard Creek where a decline was documented. Average bottom concentrations in St. Leonard Creek have historically been lower than the other creeks, remaining below 5.0 mg L^{-1}, and are often near or below hypoxic conditions (< 2.0 mg L^{-1}). Average bottom water dissolved oxygen has remained above the hypoxic threshold for the past 3 years. Concentrations of dissolved oxygen less than 2.0 mg L^{-1} are very stressful to most organisms and should be considered dangerously low levels. The average bottom water dissolved oxygen in St. Leonard was below this limit 6 out of the 16 years monitored.

For the lower Patuxent tributary monitoring time-series, Hungerford has the highest average bottom water dissolved oxygen at 5.62 mg L^{-1}. The minimum (worse conditions) bottom water measurement (0.11 mg L^{-1}) was recorded in August 2021 on St. Leonard Creek. Similarly, low levels (0.17-0.18 mg L^{-1}) were also found on St. Leonard Creek and on Hellen's Creek on the same date. The maximum (better conditions) measurement of 9.46 mg L^{-1} occurred at Hungerford Creek in July 2024. Bottom water dissolved oxygen appears to be improving overall on the Lower Pax creeks with the exception of St. Leonard Creek which is exhibiting a decline. None of these patterns are statistically significant.

7.1.3 *Active Chlorophyll-a*

Figure 7.3

Average surface water chlorophyll-*a* concentrations for 2024 were higher than long-term averages in Island Creek and St. Leonard Creek but remained below long-term means in Hellen's Creek and Hungerford Creek. From 2018 to 2019, average surface chlorophyll-*a* increased in all creeks to concentrations greater than 20 µg L^{-1}, which is the concentration used to define an algal bloom. Annual chlorophyll averages fell below the bloom threshold in 2020 and have fluctuated since but have remained near or below 20 µg L^{-1} with the exception of Island Creek in 2024 (34 µg L^{-1}). Hellen's Creek (HLN3) had the highest long-term average (33.05 µg L^{-1}) due to an algal bloom in June 2011 resulting in the time-series maximum (worst) concentration of 946 µg L^{-1}. The time series minimum (best conditions) surface water chlorophyll-a measurement was 5 µg L^{-1} in St. Leonard Creek in August 2022. Surface water chlorophyll-*a* appears to be declining (improving conditions) in all creeks except for Hungerford which exhibits a slight increase in chlorophyll-a concentrations (worsening). These patterns are not statistically significant.

Island Creek

Mean = 0.76 m

St. Leonard Creek

Mean = 0.98 m

Hellen's Creek

Mean = 0.76 m

Hungerford Creek

Mean = 0.59 m

Mean Secchi Depth, m

Year

Figure 7.1 Bar graphs indicating summer mean water clarity as Secchi disk depths in the lower Patuxent River Creeks. Comparisons are made between data collected during summer periods of 2009-2024. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long-term tributary average. "ND" indicates tributary was not sampled these years.

Figure 7.2 Bar graphs indicating summer mean bottom water DO concentration (mg L^{-1}) in the lower Patuxent River creeks. Comparisons are made between data collected during summer periods of 2009-2024. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average. ND indicates tributary was not sampled these years.

Island Creek

Mean = 25.63 µg/L

St. Leonard Creek

Mean = 16.18 µg/L

Hellen's Creek

131 µg/L

Mean = 33.05 µg/L

Hungerford Creek

Mean = 29.92 µg/L

ND ND ND

Mean Surface Active Chlorophyll, µg/L

Year

Figure 7.3 Bar graphs indicating summer mean surface water chlorophyll-*a* concentration in the lower Patuxent River Creeks. Comparisons are made between data collected during summer periods of 2009-2024. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average. ND indicates tributary was not sampled these years. *Note that in 2011 mean surface chlorophyll-a levels were 131 µg L^{-1}.

7.2 Upper Patuxent Tributary Comparisons

7.2.1 *Water Column Clarity using Secchi Disk Readings*
Figure 7.4

The year 2024 was the 15th year of monitoring the upper Patuxent Creeks. Yearly summer average water clarity for these tributaries was lower than in the lower Patuxent Creeks, ranging from 0.4 to 0.6 m over the time series. These measurements indicate poor water clarity and would not normally be associated with SAV communities. However, these creeks are quite shallow and thus enough light can reach the bottom so that some SAV species are able to grow in these turbid but shallow waters. In addition, some of these freshwater SAV species are canopy forming types and because a portion of the plant grows along the surface of the water, adequate light is available.

Water clarity decreased in Hall Creek over from 2010 to 2015 but stabilized in 2017. In 2024, average water clarity increased to above the long-term average in Hall Creek while Hunting Creek and Battle Creek averages declined to below the long-term average. In the fifteen years of sampling, the minimum (poor water clarity) Secchi disk measurement was (0.1 m) recorded on Hunting Creek in June 2019. The maximum (better water quality) measurement of 1.4 m occurred on Hall Creek in August 2010. Over the time series, water clarity appears to be degrading in Hall and Hunting Creek while Battle Creek exhibits improving water clarity. None of these patterns are statistically significant.

7.2.2 *Dissolved Oxygen*
Figure 7.5

All creeks have average bottom water concentrations above the hypoxic threshold of 2 mg L^{-1}. Average concentrations increased in all creeks in 2024 and were slightly higher than their long-term annual means with the exception of Hunting Creek. Although Hall Creek and Hunting Creek have experienced multiple drops in average bottom water concentration over the time-series, an overall increase has been observed in both creeks since 2010. In contrast, average bottom water dissolved oxygen in Battle Creek has experienced an overall decrease since 2011 and was below the long-term mean from 2018 to 2022 with the lowest annual mean (2.58 mg/L) occurring in 2021. The time-series minimum (worst conditions) bottom water DO measurement (0.92 mg L^{-1}) occurred in Battle Creek in July 2015. The maximum (best conditions) measurement of 9.04 mg L^{-1} was recorded in Hall Creek in June 2014. None of these patterns are statistically significant.

7.2.3 *Active Chlorophyll-a*
Figure 7.6

Average surface chlorophyll concentrations in the Upper Patuxent Creeks were above their respective long-term means, and were above the threshold for algal blooms (20 μg L^{-1}). Hall Creek and Battle Creek experienced increases in average concentrations from 2023 to 2024 while a decline was indicated at Hunting Creek. There appears to be a

slight increase in average chlorophyll in all three creeks but these patterns were not statistically significant. The time-series minimum (better conditions) surface water chlorophyll-*a* measurement was 4.54 µg L^{-1} in Hall Creek in August 2010. The maximum (worse conditions) measurement was 195.28 µg L^{-1} in Hunting Creek in June 2019.
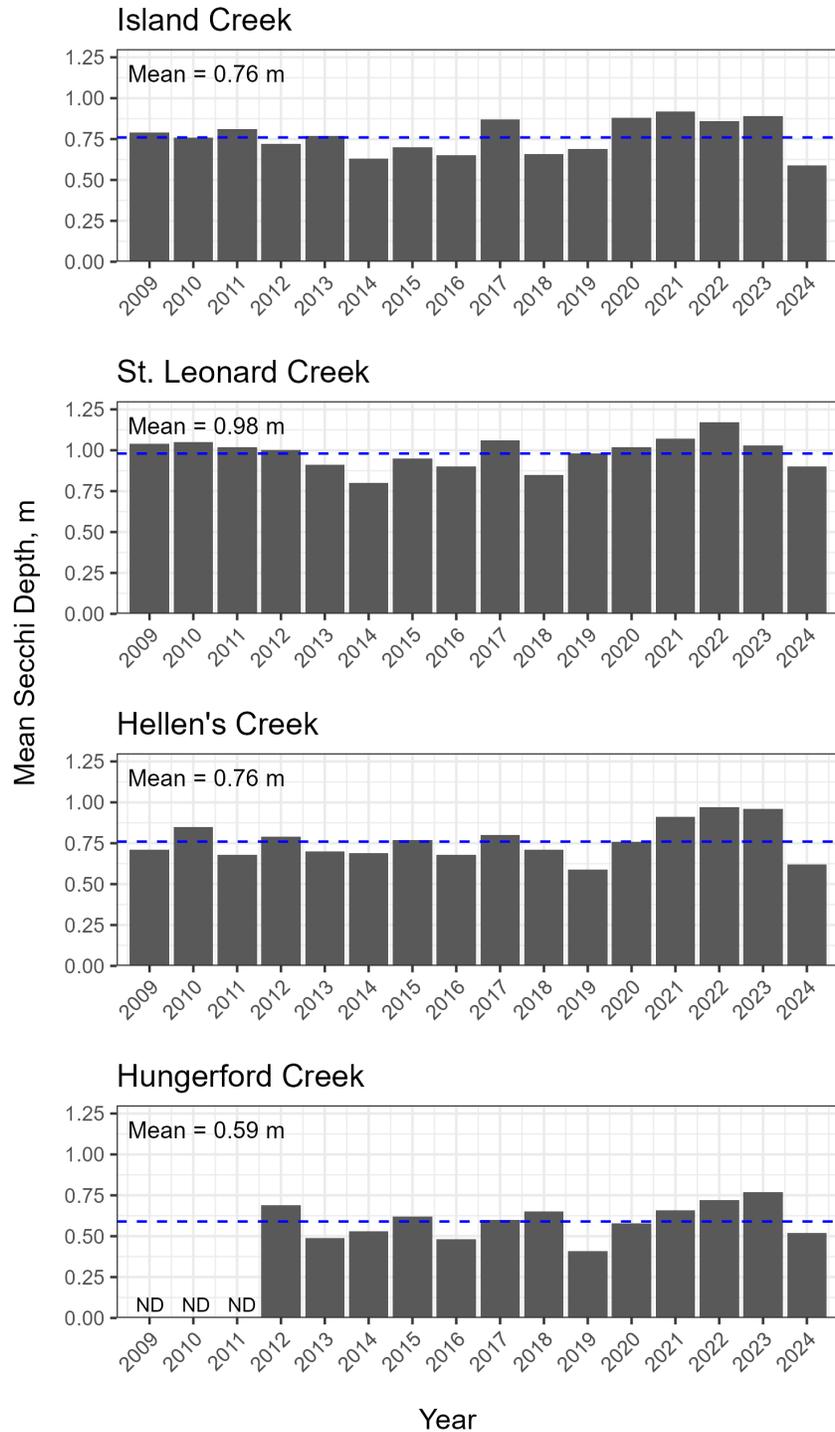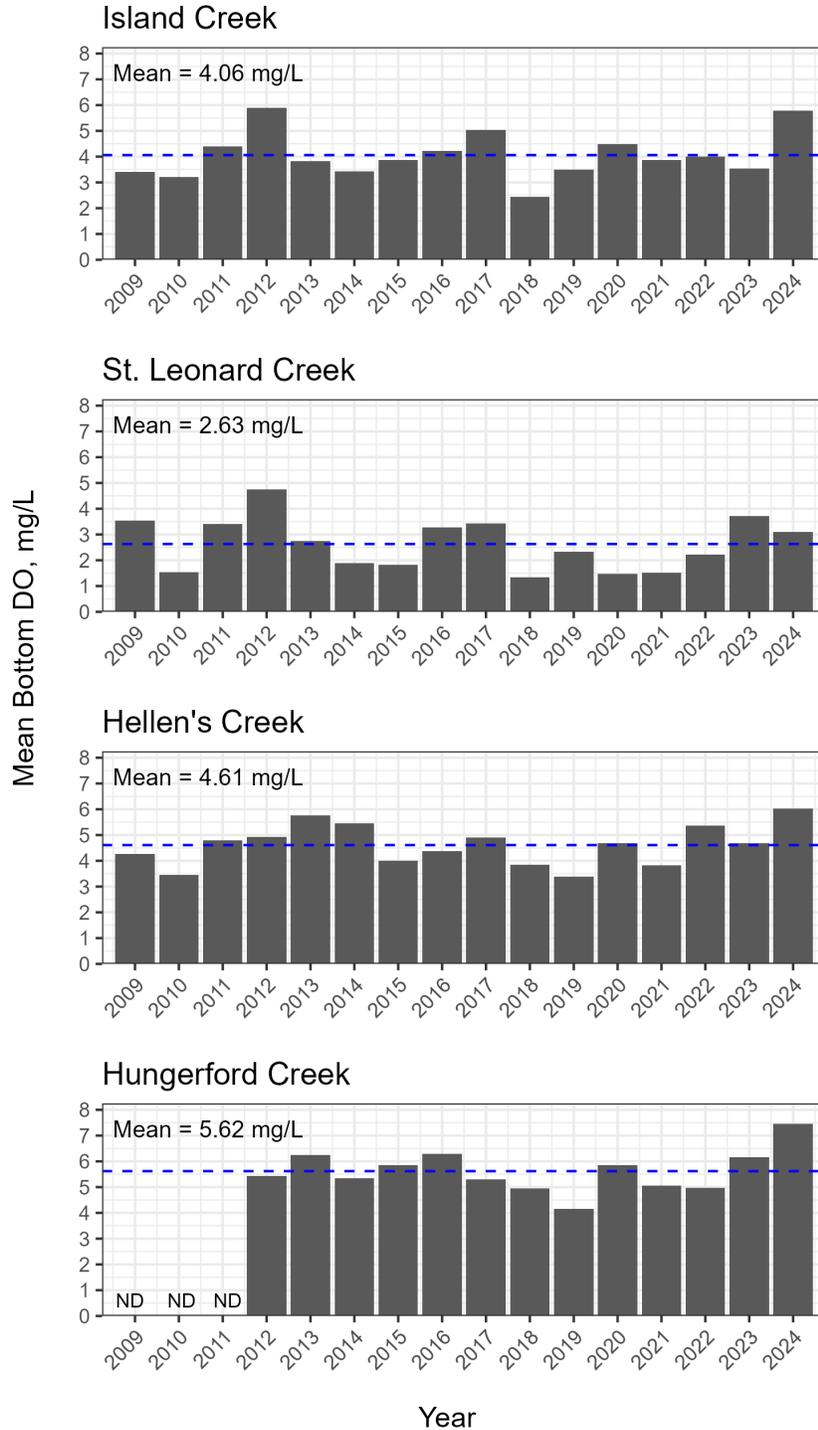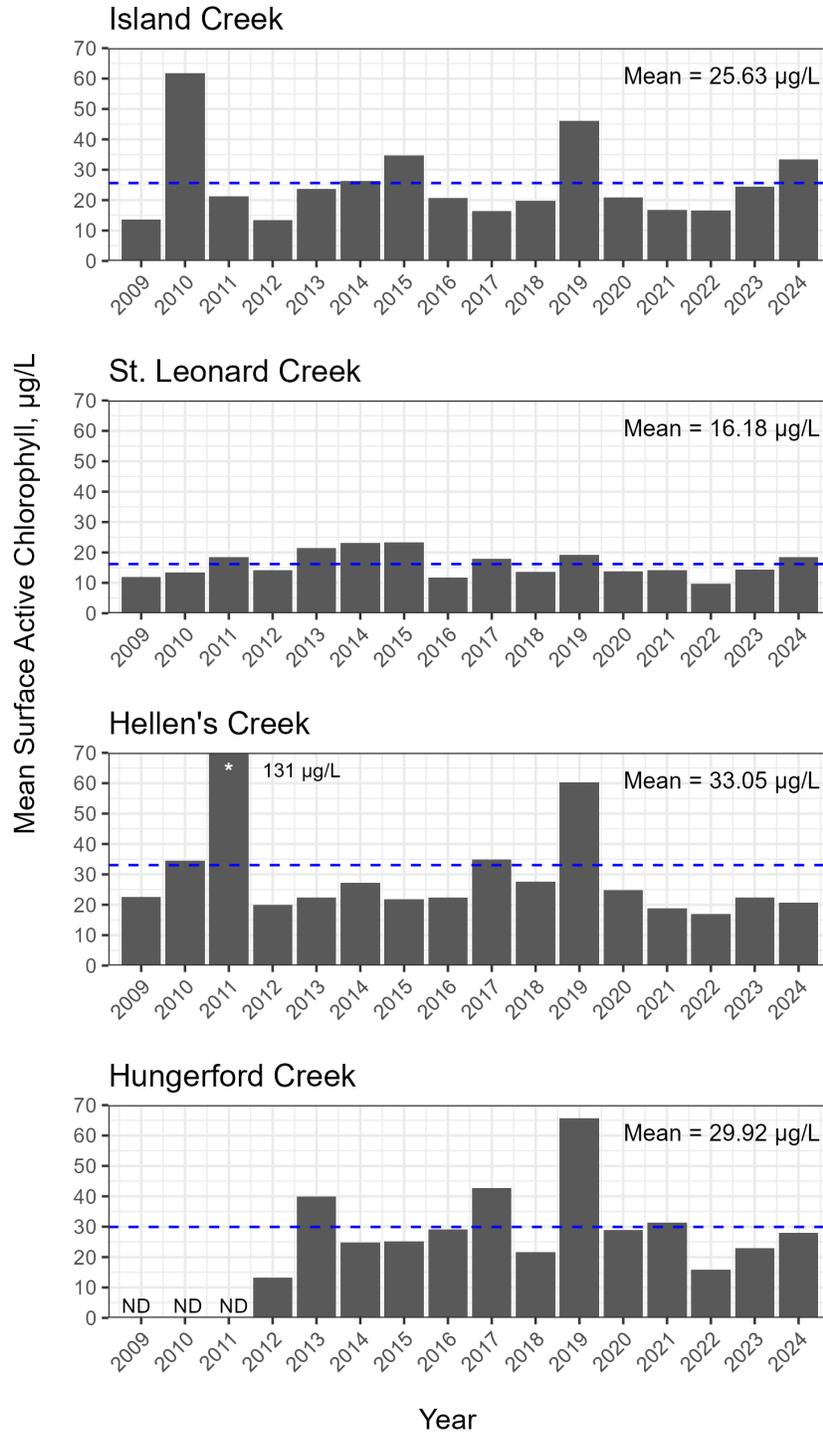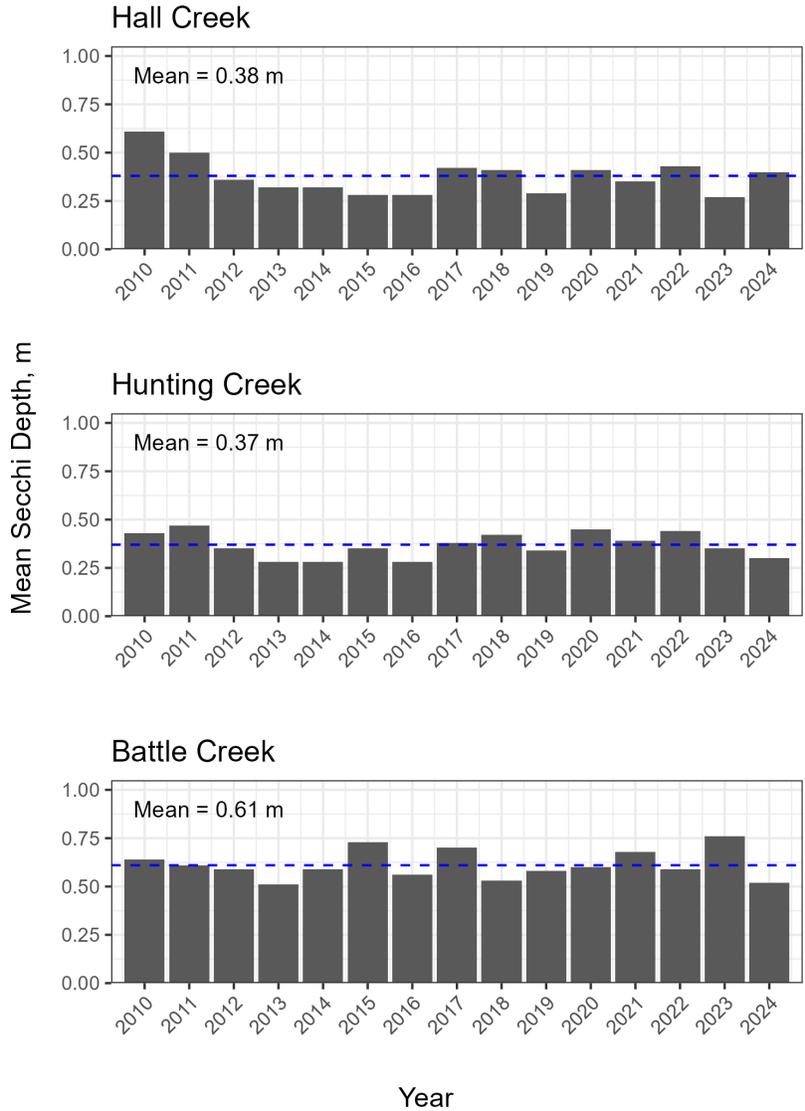

Figure 7.4 Bar graphs indicating summer mean water clarity as Secchi disk depths in the upper Patuxent River Creeks. Comparisons are made between data collected during summer periods of 2010-2024. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average.

Figure 7.5 Bar graphs indicating summer mean bottom water DO concentration in the upper Patuxent River Creeks. Comparisons are made between data collected during summer periods of 2010-2024. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average.

Hall Creek

Mean = 26.94 µg/L

Hunting Creek

Mean = 35.06 µg/L

Battle Creek
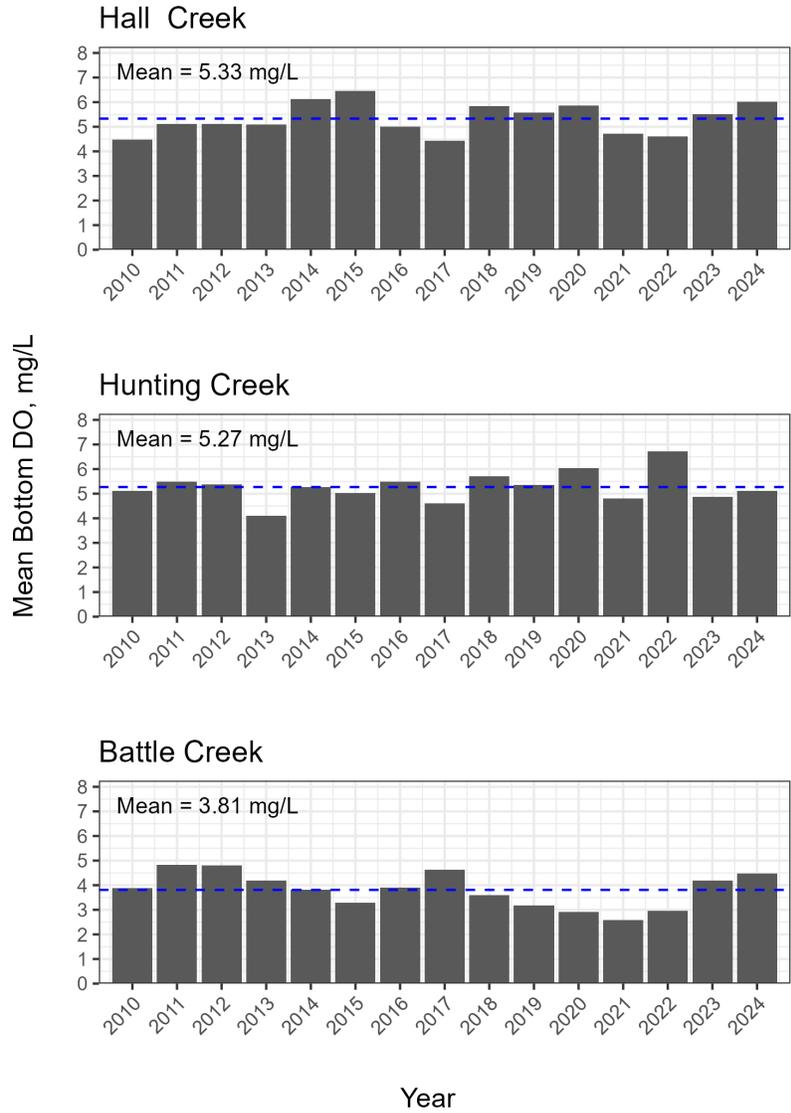
Mean = 21.87 µg/L

Year

Figure 7.6   Bar graphs indicating summer mean surface water chlorophyll-*a* concentration in the upper Patuxent River creeks. Comparisons are made between data collected during summer periods of 2010-2024. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average.

7.3   Chesapeake Bay Western Shore Tributary Comparisons

7.3.1   *Water Column Clarity using Secchi Disk Readings*

Figure 7.7

The 2024 summer marked the fourteenth year of monitoring of the Western Shore creeks and the twelfth year monitoring Parkers Creek. Average Secchi Disk measurements over the time-series ranged from 0.36 to 0.99 m. In 2024, Secchi Disk measurements in the creeks declined slightly to below their respective long-term means. These measurements indicate poor water clarity and would not normally be associated with SAV communities.

Fishing Creek, Plum Point Creek and Parkers Creek have exhibited relatively stable average water clarity over the time series.

Water clarity at Flag Harbor was variable the first few years but also appears to have stabilized since around 2015 and is generally better (long-term mean of 0.8 m) than the other Western Shore Creeks (0.5 to 0.6 m). The time-series minimum (poorest water quality) Secchi Disk measurement was 0.05 m in Parkers Creek in July 2014. The maximum (best water clarity) Secchi disk measurement (1.8 m) occurred in Parkers Creek in June 2021.

7.3.2 *Dissolved Oxygen*
Figure 7.8

Average bottom water dissolved oxygen concentrations increased in all Western Shore creeks in 2024 and were above their respective long-term averages. Over the time-series, average bottom water concentrations in the Western Shore creeks has remained above 2 mg L^{-1} but often fell below the desired oxygen concentrations of 5 mg L^{-1} for these environments. The time-series minimum (worst conditions) bottom water measurement was 0.07 mg L^{-1} in Parkers Creek in September 2021. The maximum (best conditions) measurement of 10.26 mg L^{-1} occurred in Parkers Creek in August 2016. Bottom water dissolved oxygen in the Western Shore creeks appears to be improving in Plum Point Creek, Fishing Creek, and Flag Harbor, but is degrading in Parkers Creek. None of the patterns are statistically significant.

7.3.3 *Active Chlorophyll-a*
Figure 7.9

Average surface water chlorophyll- *a* was above the bloom threshold (20 µg L^{-1}) at all Western Shore creeks in 2024. Fishing Creek, Plum Point Creek, and Parkers Creek increased to levels above their respective long-term averages while Flag Harbor experience a decline in chlorophyll concentrations and remained below the long-term mean. Parkers Creek generally exhibited small fluctuations in mean surface chlorophyll-*a* over the time series and maintains the lowest long-term average (18 µg L^{-1}) of the Western Shore creeks although a more pronounced increase in average concentration (39 µg L^{-1}) was indicated in 2024. Plum Point Creek had the highest long-term average (40 µg L^{-1}) of the Western Shore creeks. The time series minimum (best conditions) surface water chlorophyll-*a* measurement was 0.23 µg L^{-1} in Parkers Creek in June 2013. The maximum (worst conditions) measurement was 177.6 µg L^{-1} on Plum Point Creek in August 2018. Surface water chlorophyll appears to be declining (improving conditions) in Plum Point Creek and Fishing Creek over the time series, while Flag Harbor and Parkers Creek exhibited a slight increase in concentrations (degrading conditions). None of these patterns are statistically significant.
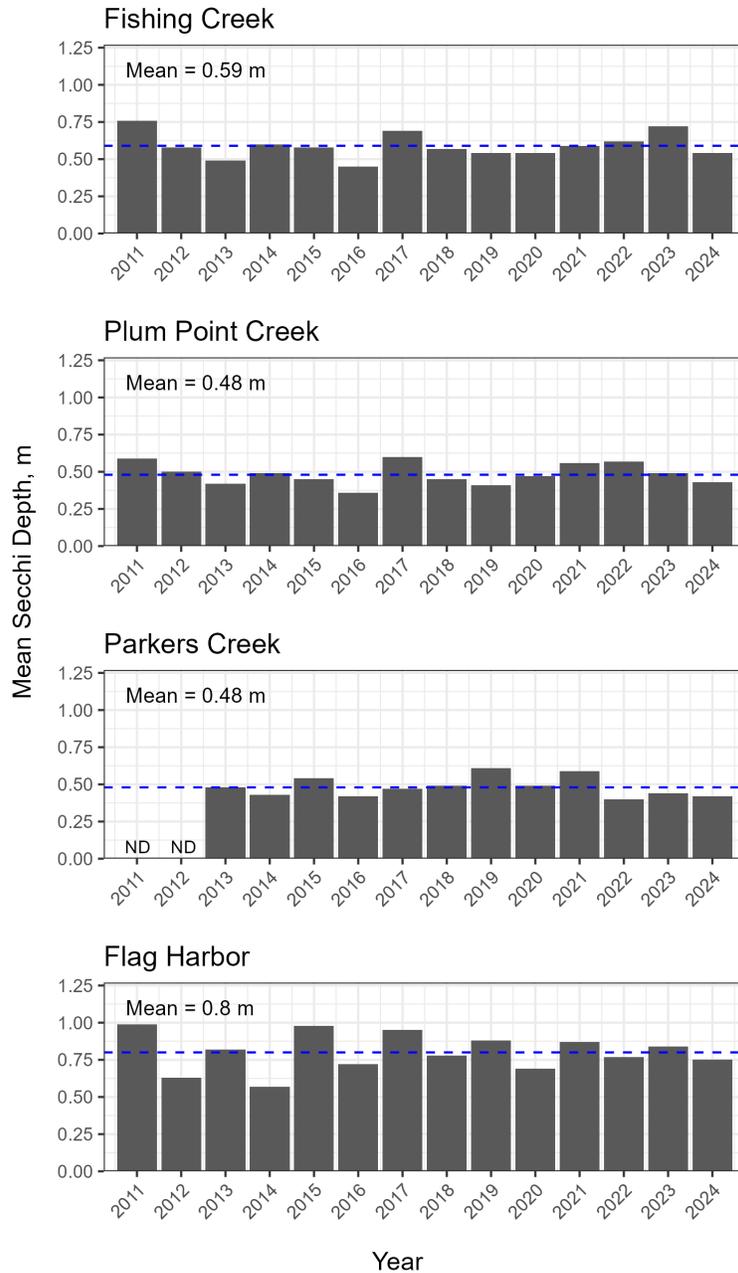
Figure 7.7 Bar graphs indicating summer mean water clarity as Secchi disk depths in the Western Shore creeks. Comparisons are made between data collected during summer periods of 2011-2024. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average. ND indicates tributary was not sampled these years.
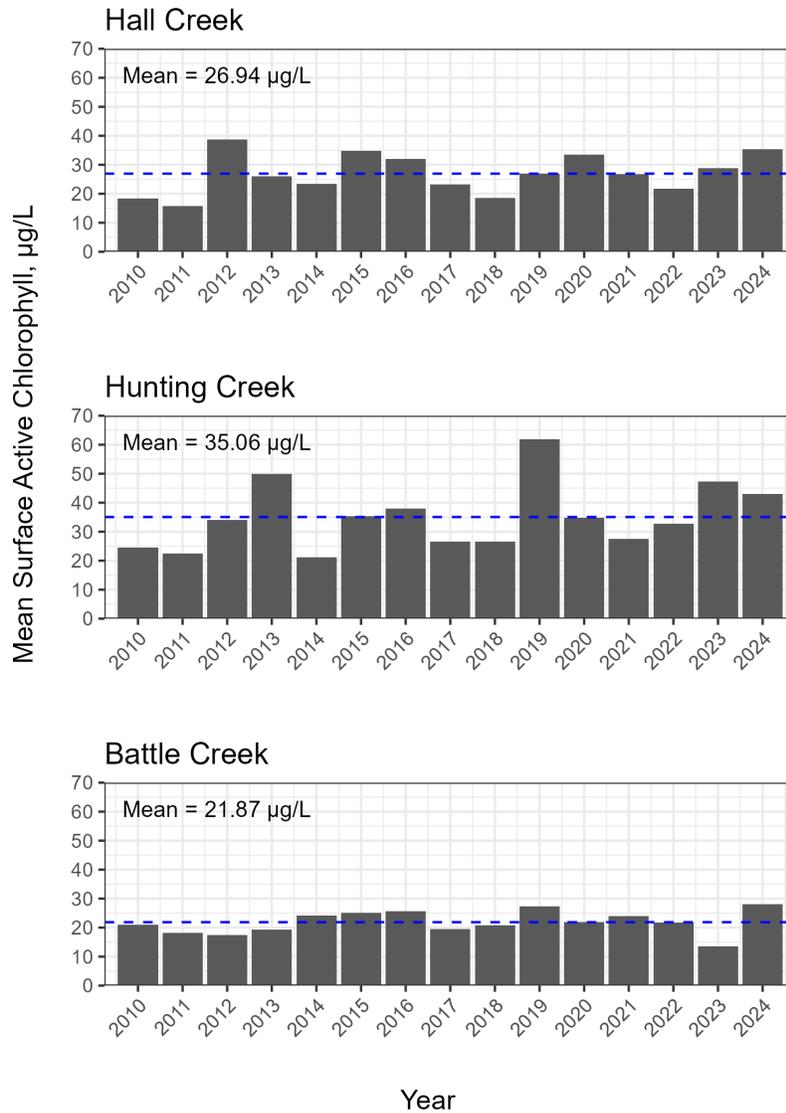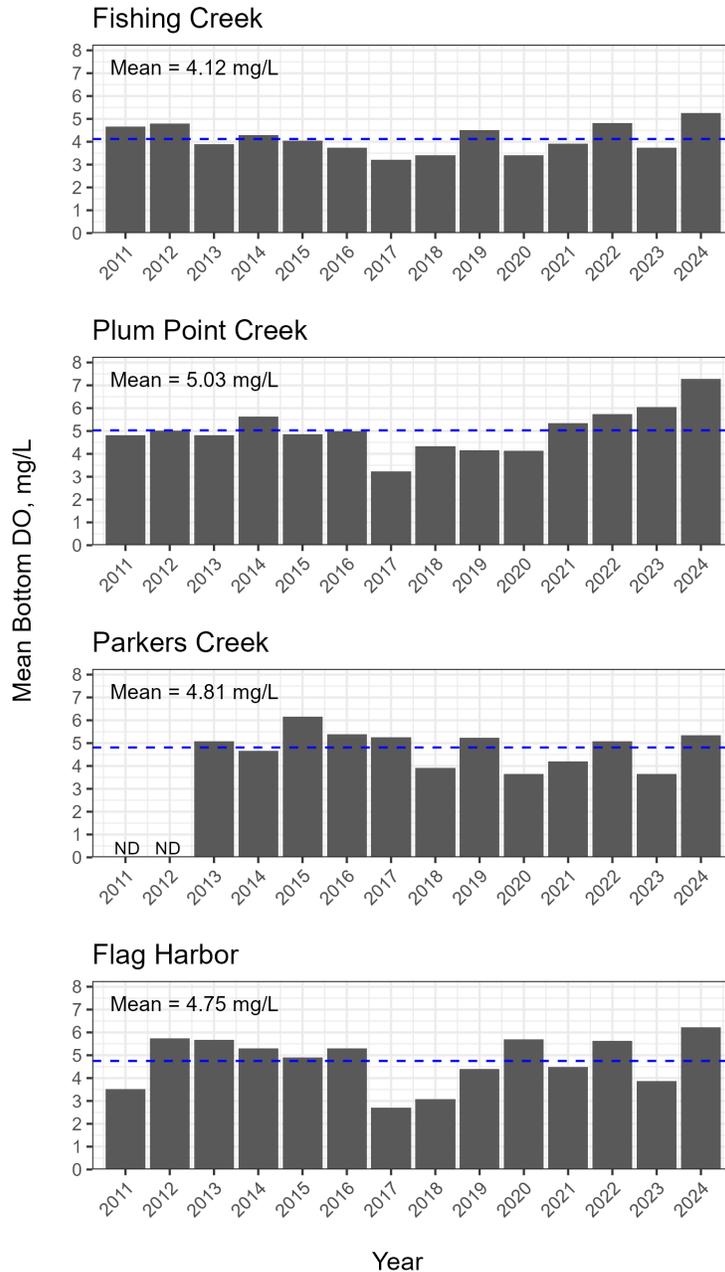
Figure 7.8 Bar graphs indicating summer average bottom water DO concentration in the Western Shore creeks. Comparisons are made between data collected during summer periods of 2011-2024. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average. ND indicates the tributary was not sampled these years (2011-2012).

Figure 7.9 Bar graphs indicating summer mean surface chlorophyll-*a* concentration in the Western Shore Creeks. Comparisons are made between data collected during summer periods of 2011-2024. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average. ND indicates tributary was not sampled these years.
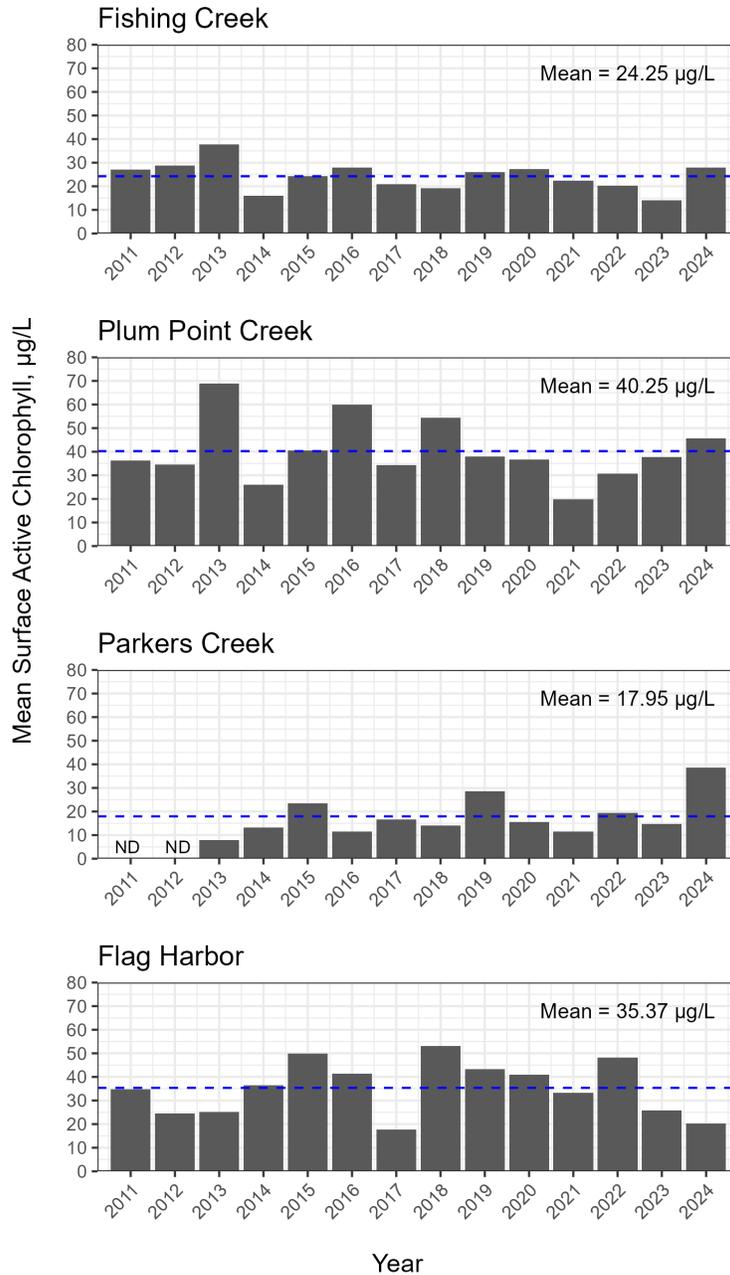
8 Tidal Creek Trends Compared to Mainstem Stations Trends

The Chesapeake Bay Program (CBP) has a long-term monitoring program of the Chesapeake Bay and its tributaries. In the Patuxent River and the western Bay surrounding Calvert County, there are 9 stations that have been monitored from 1985 to present by the Maryland Department of Natural Resources as a part of this program. Chesapeake Biological Laboratory (CBL) began monitoring three smaller tributaries in 2009. Additional tributaries were added each year from 2010 to 2013 and continue to be monitored providing a higher resolution at 32 stations.

CBP uses statistical techniques called "Generalized Additive Models" (GAMS) to quantitatively assess trends over time in the monitoring data. GAMs are capable of capturing nonlinear patterns and therefore more likely to reveal improving or declining trends. Here we ran this model on the same years (2013 to 2024) and months (June through August) for both the Calvert Creek (CBL) and the CBP stations specifically for Secchi depth, surface chlorophyll-*a*, and bottom water dissolved oxygen to compare these smaller systems versus the larger adjoining systems. GAMS also gives us an understanding of how all systems have changed with time. Monitoring of the most recently added creek began in 2013, the starting time for the series analysis.

8.1 Secchi Depth

Figure 8.1

**Figure 8.1 Possible trends for Secchi disk depth for the summer months ~2013-2024.
Solid circles = CBL sites, white circles with black dots = DNR sites.**

Most stations measured in our county monitoring exhibited "no trend" in Secchi depth over the time series (2013-2024). However, positive trends indicating improving water clarity were seen on the two lower stations of Hall Creek (HAL1, HAL2), on the mid station of St. Leonard Creek (SLC2). Positive trends were also indicated at three CBP mid-channel stations upriver from Hunting Creek (TF1.7), just north of Point Patience (LEI.3), and on Chesapeake Bay just north of Plum Point Creek (CB4.2W). All trends were statistically significant.

8.2   Chlorophyll-*a*

Figure 8.2

Figure 8.2 Possible trends for surface chlorophyll-*a* for the summer months ~2013-2024.
Solid circles = CBL sites, white circles with black dots = DNR sites.

While most stations measured in our county monitoring indicated "no trend" for chlorophyll concentrations, declining concentrations (an improvement in water quality for this variable) were indicated for the mid and upstream stations on St. Leonard Creek (SLC2, SLC4). Increasing chlorophyll concentrations (a decline in water quality) were indicated at the mid and upstream stations of Parkers Creek (MC, BS). All trends were statistically significant.

8.3 Dissolved Oxygen

Figure 8.3

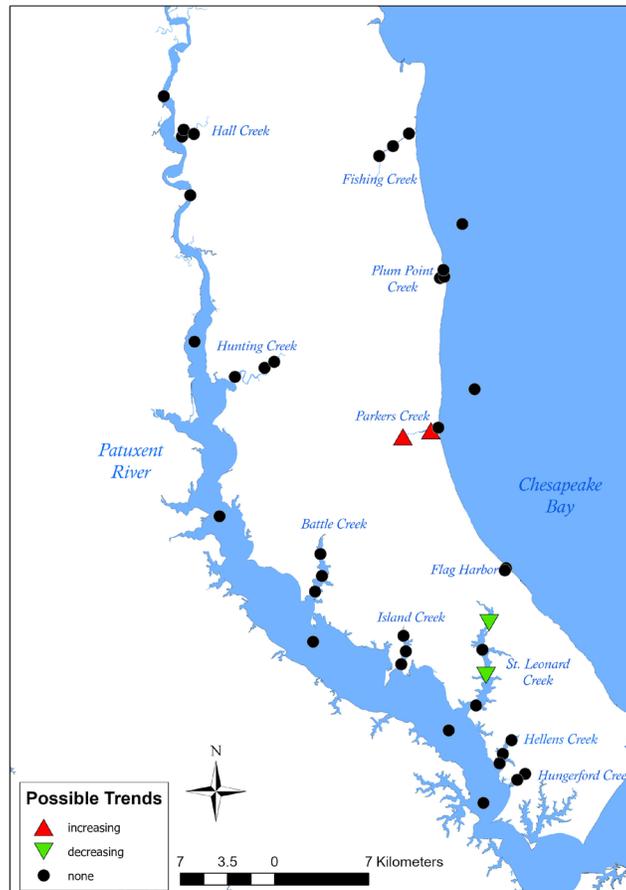**Figure 8.3 Possible trends for bottom DO for the summer months ~2013-2024.**
Solid circles = CBL sites, white circles with black dots = DNR sites.

Most stations measured in our county monitoring indicated "no trend" for bottom water dissolved oxygen for the time period of 2013-2024 with the exception of the mid-creek station on Plum Point Creek (PLM2) where an improvement is indicated over time (positive trend, statistically significant).

Although improvement in a single water quality parameter is indicated at some sites, the overall finding of the trend analysis is that the majority of CBL and CBP sites are not demonstrating significant change over the past 12 years.

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